



Panel to Review EOSDIS Plans

Final Report

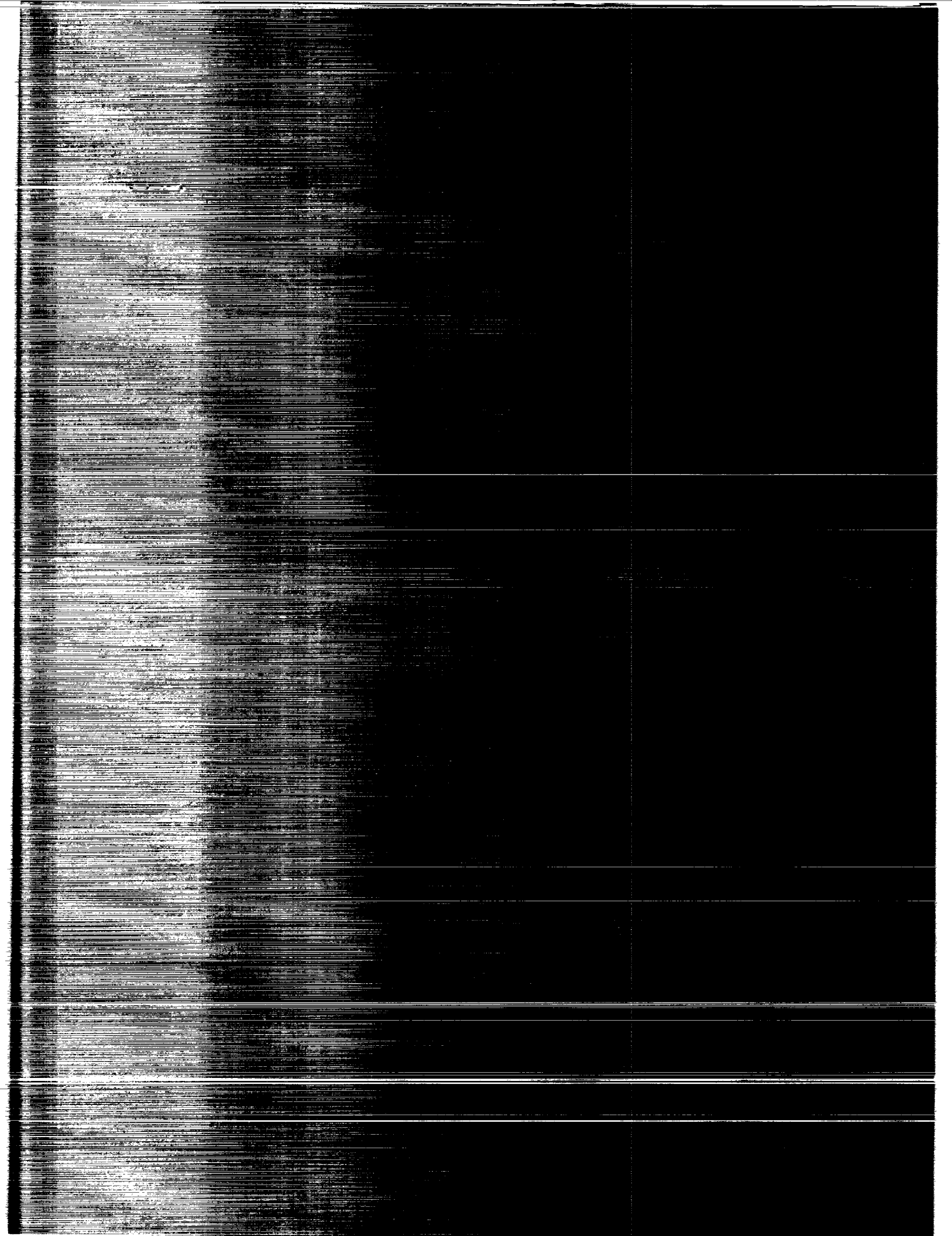
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National Research Council



Panel to Review EOSDIS Plans

Final Report

Commission on Physical Sciences, Mathematics, and Applications

National Research Council

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NATIONAL RESEARCH COUNCIL

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OFFICE OF THE CHAIRMAN

January 11, 1994

Mr. Daniel S. Goldin
Administrator
National Aeronautics and
Space Administration
Two Independence Square
300 E Street SW
Washington DC 20546

Dear Mr. Goldin:

I'm pleased to transmit the third and final report of the National Research Council Panel to Review EOSDIS Plans. As you know, the Panel has previously produced both an interim and a letter report, commenting on several aspects of EOSDIS, including its management, architecture, goals, and relation with potential users.

This report departs from the previous two in that it reflects information that became available only after contractor selection for the EOSDIS Core System was completed. The Panel subsequently benefitted from the briefings by and discussions with staff from the Hughes Information Technology Company, as well as further discussions with officials from both NASA Headquarters and the Goddard Space Flight Center.

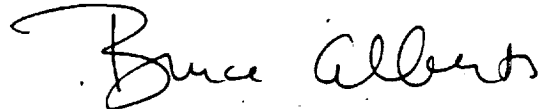
As the report states, the Panel is very pleased by NASA's response to many of its recommendations, and shares with NASA the belief that EOSDIS is now in many respects a stronger system. The care with which NASA staff examined the Panel's recommendations and acted upon them reflects a high degree of professionalism and dedication to public service in which NASA should rightly take great pride.

At the same time, this report sets out the Panel's view that if planning for EOSDIS continues along its current trajectory, it will fall far short of providing potential users with the data in the form and flexibility needed to exploit the great investment being made in the Earth Observing System. The Panel accordingly both delineates its concerns and offers recommendations for addressing them.

I therefore commend these judgments and recommendations to you, and look forward to your comments. The National

Research Council is grateful to NASA for the confidence in its work that this important task implied. Finally, I hope you will second my appreciation to the Panel, and especially its Chair, Mr. Charles Zraket, for a job well done.

Sincerely,

A handwritten signature in cursive script that reads "Bruce Alberts".

Bruce Alberts
Chairman

cc: Dr. Charles Kennel
Dr. Dixon Butler
Mr. Charles Zraket
EOSDIS Panel

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Preface

This document is the final report of the Panel to Review EOSDIS Plans. The main part conveys to NASA the panel's findings and recommendations on its 1993 review of the development effort for the EOSDIS Core System. For completeness, the document also contains copies of the panel's earlier two letter reports (April and September 1992) as addenda.

Although this report and the panel's previous letter reports are critical of NASA's development effort for EOSDIS, we believe that if NASA makes the necessary changes to the development program, it will ultimately be able to build an information system that will meet users' needs and provide the nation with a superb tool to utilize global change research information to the fullest extent.

NASA was very helpful in providing information and resources to the panel throughout its deliberations. The agency was also highly responsive to the panel's recommendations, advice, and suggestions. NASA appears to be implementing the necessary changes to EOSDIS even as this report is being prepared. The panel offers special thanks to Dixon Butler, director of the Operations, Data, and Information Systems Division of the Office of Mission to Planet Earth. Much of NASA's responsiveness has been due to his leadership.

I would like to thank the members of the panel for their insights and hard work, often under difficult time constraints, in conducting this review. It should be noted that a number of changes in the panel's membership occurred over the course of the review. D. James Baker left the panel in 1993 to become under secretary of commerce for oceans and atmospheres and administrator of the National Oceanic and Atmospheric Administration; Anita K. Jones left in 1993 to become director of defense research and engineering. Two other members changed positions during the period of the review: Kenneth I. Daugherty was promoted to deputy director of the Defense Mapping Agency; Gael F. Squibb returned to the Jet Propulsion Laboratory to become manager of the Mission Operations Development Office. To provide additional expertise in the area of earth science data users, several new members joined the panel during 1993: Mark R. Abbott, Elaine R. Hansen, and Roy L. Jenne. Finally, Edward D. Lazowska joined the panel to maintain our expertise in computer science.

There are a number of other people we would like to thank for assisting the panel in its deliberations, including, from the EOSDIS project at GSFC, John Dalton, Robert Price, Gail McConnaghy, H. K. Ramapriyam, and Mel Banks; from Hughes, Marshall Caplan, Saul Volansky, William Dahl, and Anthony Calio; from NOAA, D. James Baker and Gregory Withee; and from CIESIN, Roberta Miller, Jack Eddy, Carol Hood, and T. Fletcher.

Finally, I would like to thank the staff of the National Research Council (Richard C. Hart, Anne Linn, James E. Mallory, Norman Metzger, and Carmela Chamberlain) for their assistance in organizing our meetings and in preparing our reports, and for seeing to all of the necessary details that made the work of the panel possible.

Charles A. Zraket

Chair, Panel to Review EOSDIS Plans

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1. Introduction and Summary

Formed in January 1992, the Panel to Review EOSDIS Plans was charged with advising NASA on its plans for developing the Earth Observing System (EOS) Data and Information System (EOSDIS). Specifically, the panel was asked to assess the validity of the engineering and technical underpinnings of the EOSDIS; assess its potential value to scientific users; suggest how technical risk can be minimized; and assess whether current plans are sufficiently resilient to be adaptable to changing technology and requirements such as budget environments, data volumes, new users, and new databases.

The panel completed an interim report (Addendum A) and transmitted it to NASA and other interested parties in the government on April 9, 1992. Because of a delay in NASA's plans to select the contractor for EOSDIS, the panel was not able to complete its review of the program according to the original government request. With the issuance of a letter report (Addendum B) on September 28, 1992, the panel became inactive until such time as NASA could release the details of the contractor's proposed architecture, schedule, and costs for developing EOSDIS. In early 1993, NASA awarded the contract for the EOSDIS Core System (ECS) to Hughes Applied Information Systems, Inc. On April 20, 1993, NASA asked the panel to reconvene to (1) complete its review of NASA's approach to the EOSDIS architecture and implementation, (2) appraise NASA's responses to the panel's previous recommendations, and (3) review the planning for EOSDIS in the context of NASA's role in the Global Change Data and Information System (GCDIS) implementation plan. To respond to the NASA charge, the panel met three times in 1993 (June 30-July 1, July 28-29, and September 1-2), including sessions with NASA officials and the EOSDIS contractor. In addition, several of the panel members visited individual Distributed Active Archive Centers (DAACs) to obtain additional views of EOSDIS.

The panel has now obtained substantial information on the EOSDIS budget, contractor work program, and current baseline architecture that was not previously available, due to procurement restrictions. This report presents the panel's findings and recommendations based on this additional information. Following the summary of the major findings and recommendations, the underlying analysis and other information are presented in the body of the report.

ESSENTIAL FINDINGS

1. The EOSDIS now being planned is unlikely to fulfill the requirements of its intended users¹ and its original goals. The current design and development activities of EOSDIS have focused primarily on receiving, processing, and storing data acquired by EOS and other NASA satellites and on the conversion of the data to geophysical parameters using high-quality algorithms developed by flight instrument investigator teams. The design appropriately takes into account the need to rapidly process large volumes of data from the planned EOS satellites. In essence, the largely manual system of today is being automated, which should improve the quality and the availability of data substantially. This aspect of the system has a low risk of technical failure because it relies primarily on commercial, off-the-shelf software. It has a high risk of failure as a system for the intended users, however, because it is a centralized system that will likely be unable to keep up with the inevitable changes in technology and in user needs over time.

As currently planned, EOSDIS is simply an automated data distribution system. While the heart of the system--the EOSDIS Core System (ECS)--will incorporate data from multiple sources, especially the EOS instruments, those data will be provided to users as "standard products" via an architecture that is highly centralized. Thus, there will be severe limits on the users for whom the system was designed: they will not easily be able to automatically combine data from different sensors, alter the nature of the products to meet new scientific needs, or revise the algorithms used to process data for different purposes. The present approach of developing standard data products is too rigid to support the scientific community for which EOSDIS is being built.

2. The present design for the EOSDIS Core System relies on principles for implementing large, centralized data systems that are either outdated or will quickly become so. Modern techniques of systems design indicate that a logically distributed architecture is crucial to an evolutionary system like EOSDIS, which must be changed and added to many times during its lifetime. Thus, current approaches to designing information systems emphasize open, extensible architectures. The Internet and its

¹Throughout this report, unless otherwise noted, the panel defines "users" as scientists involved in the EOS project; scientists currently active in global climate change research or global change research in general; scientists engaged in earth science research; and analysts who would use earth science research results for policy-oriented studies.

related services--in particular the Wide-Area Information Servers (WAIS), gopher, and the World-Wide Web (WWW)--are prime examples of such an architecture. In addition, a number of standards and specifications for such logically distributed systems are being developed in the commercial domain (e.g., the Distributed Computing Environment (DCE) standard and the Object Management Group's Common Object Request Broker Architecture (CORBA)) that will serve to make open, distributed systems even easier to implement in the future.

Such evolutionary and distributed development will be required by science users over the lifetime of the ECS in order to maintain a dynamic interaction between research needs and a data system designed to meet those needs. A similar interaction must take place between science users and policy analysts who will use research results to assess social and economic impacts. The current design, however, is a centralized architecture, from which data and products are geographically distributed to the DAACs. This system will severely hamper the ability of DAACs, which are intended to be the centers of disciplinary expertise, to serve their user communities, both scientific and policy oriented, through the rapid addition of new algorithms and information products unique to a DAAC.

3. NASA has been responsive to many of the panel's previous recommendations on program management, program organization, and the addition of a computer science component. The panel continues to be concerned, however, by the management structure for EOSDIS: lines of authority within the project are overly complicated, there continues to be a lack of senior personnel with experience in large-scale information system development or experience with the science, critical leadership positions are vacant, and the direct involvement of the earth science community in the EOSDIS project remains more advisory than tangible. Also, sufficient system engineering expertise is lacking at the project level.

4. The DAACs are not adequately incorporated into the management of the ECS and are not adequately empowered to represent their user communities:

- The DAACs and the users will receive data in forms over which they will have little control and which may be difficult to manipulate;
 - The DAACs will have little control over the management of the ECS or its future evolution; and
-

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- The DAACs will have little if any budgetary control and only an advisory or marginal role in guiding and developing the overall system evolution.

5. It does not appear that NASA has given adequate attention to defining the users, the ways they expect and want to interact with the system, and the kinds of information they will need. Rather than conduct a large survey of users, NASA should define users' present idea of the user model and have it reviewed by the DAAC advisory panels. This model should outline a few levels of service and give approximate costs for each.

6. The present program does not give adequate attention to the development of higher-order data products (levels 3 and 4). NASA has also recently reduced the number of data products being produced by the system. Further, it appears that the plans to reprocess and reanalyze data sets are inadequate. Collectively, the functional capability of this aspect of the system will probably not meet the requirements of users.

7. NASA still needs to develop a definite and comprehensive plan for long-term archiving and storage of EOSDIS data.

8. A substantial investment is being made within EOSDIS through the Pathfinder program to reprocess data from NASA and NOAA satellites flown over the last two decades. This program is expected to provide much improved long-term data sets that are essential for global change research.

CONCLUSIONS AND RECOMMENDATIONS

Major revisions of the EOSDIS Core System (ECS) are urgently needed, specifically in its architecture, its leadership, and its empowerment of its users. The system currently being built will not meet the needs and expectations of its user community. Its usefulness will diminish as technology, networks, and user needs evolve and changes must be made rapidly and economically. The panel therefore recommends the following:

1. The EOSDIS Core System should be redesigned around an architecture that is logically distributed and whose products are designed and controlled in part by the scientific and other "customers" of the system, especially those involved with the Distributed Active Archive Centers and the Science Computing Facilities being furnished by the project to the principal investigators. A logically distributed system has a lower risk of failure than a centralized architecture, because it has working
-

components being improved and operated in environments most conducive to their efficiency. The components need to be seamlessly integrated into a common system.

2. The new architecture for the EOSDIS Core System must be open and fully extensible. The information management system should be structured to enhance the interoperability among the elements of the Global Change Data and Information System and the EOSDIS Distributed Active Archive Centers. Interfaces must be easily accessible for user communications as well as for data access, distribution, and processing.

3. The role of the Distributed Active Archive Centers (DAACs) must be changed and strengthened. The DAACs are the appropriate entities to represent major segments of the diverse earth science user community, which may well make varying demands on EOSDIS. The DAACs have been chosen in part to reflect this diversity. The DAACs should be given the appropriate responsibility, authority, and funding to adequately represent their user communities. They must be intimately involved in the development, maintenance, and augmentation of the EOSDIS Core System (ECS). Ideally, the ECS will supply the information infrastructure and network interoperability that will allow the diverse needs of DAACs, Science Computing Facilities (SCFs), and other users to be met. The panel reiterates its recommendation of April 1992 that DAAC development teams be formed from these users. NASA should review its existing DAACs and consider adding and/or eliminating DAACs where appropriate. Special consideration for access to retrospective, long-term operational data in the other agencies should be part of this review, as recommended by the panel in its earlier reports (Addenda A and B).

4. To implement the recommendations of this report, the EOSDIS Project Office must be strengthened by the addition of science managers as well as people having extensive information system architecture and engineering experience.

5. The data product generation system should be reexamined to determine whether an adequate number of standard level-2, -3, and -4 data products will be available to meet the needs of the users of EOSDIS. NASA should also review whether the plans for reprocessing and analysis are adequate to maintain the high-quality data sets required by the user community. The data product generation system should be adjusted so that scientists not directly involved in the EOS program can contribute to the development of new algorithms and higher-order data sets. The data product generation system

should be made more open and flexible and provide information on algorithms and higher-order data products not formally developed within the EOSDIS processing and analysis systems. The system must be flexible enough to be able to accommodate new data products that cannot yet be envisioned as being needed for global change research over the next 15 years.

6. Version 0 of EOSDIS, currently being implemented, will provide an initial product set that will supply users with an early operational capability. It should serve as a testbed for further development, rather than be discarded and replaced with a different system. This will allow the development of the EOSDIS Core System to be rational and evolutionary, providing the user community with a well-defined path to a system that will serve their needs.

7. The panel restates its belief that EOSDIS must be planned as a major part of the Global Change Data and Information System (GCDIS), to combine data from multiple national, international, and individual sources to enable the community of earth scientists and policy analysts to better conduct global change research. The panel also believes that EOSDIS and GCDIS must be able to facilitate user requirements for the addition of new data, algorithms, and data products developed outside the EOSDIS environment. The current design of EOSDIS does not address this important attribute of user-driven needs. Although it is difficult to try to predict the evolutionary path of EOSDIS over the next two decades, it is clear that it will not be able to address those user-driven needs if the architecture of EOSDIS is not logically distributed, open, and extensible. Even with such an architecture, however, NASA still needs a plan for developing new products. Flexible, new capabilities in systems are valuable only if they can be developed at reasonable costs and the functions are really needed by the users.

8. While the panel recognizes that these recommendations may have a cost impact on the project, it should not be major if much of the currently planned budget can be reprogrammed for the necessary purposes. There is a much greater risk in continuing on the present path. The EOSDIS Core System could, for example, become obsolete and ineffective in meeting the needs of the EOS project and the global change research community over the next decade and beyond.

Sections 2 through 6 of this report expand on these findings and also include supporting material that further illustrates the panel's review of EOSDIS. Section 7 discusses possible ways for EOSDIS to evolve to a more important role in the GCDIS. This follows on the

panel's recommendation in the letter report (Addendum B) of September 28, 1992, that EOSDIS be more than a program oriented solely to EOS. It must be noted, however, that while an open and extensible EOSDIS is important to a future GCDIS, it should not necessarily be the core system of GCDIS that generates all of the products required. Many of these products can be generated by several of the other agencies that are part of the overall distributed system that global change research requires. Because of the large expenditure of funds to be made on EOSDIS and the need for initiating GCDIS soon, however, every effort must be made to achieve an open, distributed, and extensible system as soon as possible and within the current EOSDIS budget.

2. Data and Information System Needs for Global Change Research

To assess the effectiveness of EOSDIS, it is necessary to relate the needs of scientific users engaged in global change research to the requirements placed on the information system. EOSDIS must foster scientific uses of EOS data and information to facilitate the goals of the U.S. Global Change Research Program. Data from EOS and non-EOS instruments must be integrated and synthesized to enable understanding of the complex feedback, climate forcing functions, and human dimensions of global change. Understanding global change will require complete synoptic observations of the Earth system, as well as high-quality, long-term data sets. Many of the necessary data sets are in the possession of government agencies other than NASA, as well as of other nations, separate research organizations, and individual researchers who possess valuable collections of higher-order data products. Documentation of long-term trends derived from a variety of these data sets will be crucial. This includes operational, in situ, space-based, and proxy data, e.g., tree rings, sea coral, and historical records. This dispersed collection of data (much of which is not in an easily accessible format) forms the foundation of many climate and other global change studies, and it will be essential for the interpretation and utilization of EOS data.

These data and information systems should bind together a complex research process that culminates in new scientific knowledge and an informed cadre of policymakers (Figure 1). Although the data requirements for global change research are not unique, they are in general more exacting than for other studies in earth science. Because global change studies involve a close coupling between data production and data use, researchers must understand the nature and quality of their data sets so that sources of error in the data production process are not confused for Earth system processes. Moreover, the natural variability of the climate system is large relative to anthropogenic climate forcing and responses to these agents of change, and so EOS and non-EOS data must be high in quality, consistently processed, and well calibrated. Global change research generally involves numerical models in which the data are either assimilated into the models or are used to test model hypotheses. These analyses usually deal with higher-order and specialized data products such as daily analyses and monthly averages. One role of EOSDIS is to make available data files and data subsets to the various data analysis efforts that are needed for global change research.

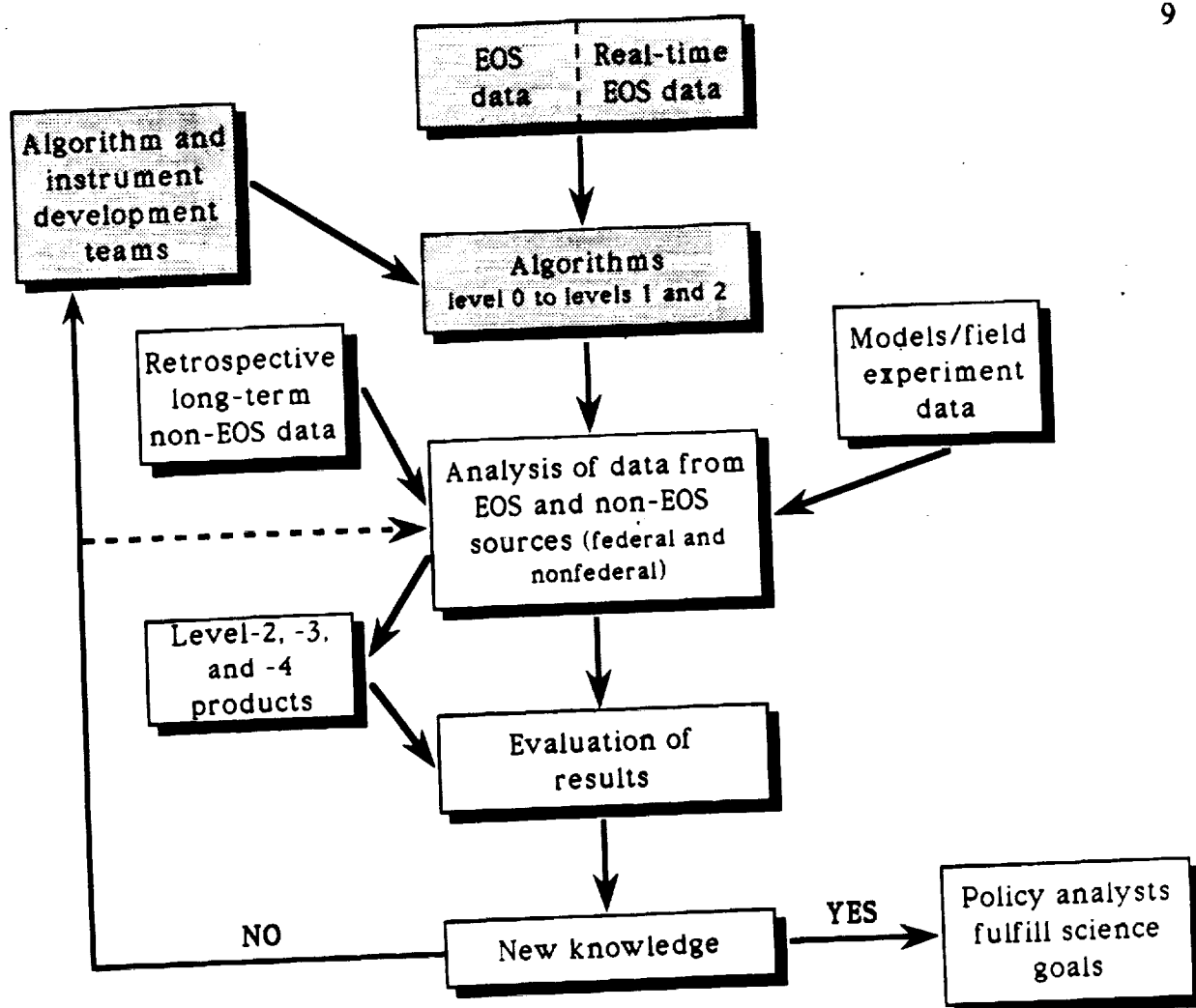


FIGURE 1 The goal of the EOSDIS project is to generate data and information needed to conduct global change research and to enable analysts to make policy decisions. EOSDIS is currently limited to the collection of EOS satellite data and the development of algorithms to create level-0, and some level-1 and -2, data products (shaded boxes). However, an open and extensible EOSDIS architecture would enable researchers to retrieve retrospective and short-term data and models from federal agencies and independent scientists and would enable them to analyze the data, generate higher-level (2, 3, and 4) data products, and evaluate the results (open boxes). If the results are poor, researchers reanalyze the data or return the algorithms for modification to NASA's algorithm and instrument development teams. Good results could lead to new knowledge and informed policy decisions.

The design, development, and operation of EOSDIS must be sensitive to the changing requirements of scientists involved in global change research as knowledge about global change increases. Scientists must be involved in all aspects of the evolving system. It appears to this panel, however, that the role of earth scientists is now limited to advisory committees--NASA has not effectively involved its earth scientists in the design, development, and operation of the EOSDIS project. Further, NASA has not structured the project in a way to involve the many excellent earth scientists at the DAACs in the most basic decisions related to design, development, and operation of the system.

Throughout the lifetime of EOSDIS, many important decisions will require the insight of earth scientists. Decisions to reprocess data with improved algorithms, to reanalyze data with improved data simulation systems to enhance products, or to set parameters for data sets will be required on a continuing basis to ensure that EOSDIS remains responsive to the needs of global change research scientists.

3. What Is EOSDIS?

As reviewed by this panel, EOSDIS is the \$2.6 billion NASA program that will provide the ground data handling, storage, and computing system for EOS and certain precursor satellites, as well as the command and control system for the EOS spacecraft. EOSDIS is expected to be the NASA part of the U.S. Global Change Data and Information System (GCDIS). Summarized below is the panel's view of EOSDIS in terms of its program elements, cost, and architecture. Section 4 summarizes the organizational structure and funding flow within the EOSDIS project.

PROGRAMMATIC DESCRIPTION

EOSDIS is a combination of activities that collectively will result in the following:

1. Capture of data from 18 EOS satellites and communication circuits to and among eight remote sites called the Distributed Active Archive Centers (DAACs). The EOS satellites will carry a total of 21 instruments and are planned to be launched between 1998 and 2012.
 2. Development of the EOSDIS Core System (ECS) that will
 - Distribute the data from the satellite data collection centers to the remotely located DAACs;
 - Provide hardware and software to store both unprocessed and processed data and provide retrieval or order capability for these data;
 - Provide the computational capabilities to convert these data into geophysical parameters using algorithms provided by EOS flight instrument investigators for higher-order data products;
 - Provide contractor staff to the DAACs, and provide software and hardware maintenance;
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- Develop and provide software capabilities for the Flight Operations System (FOS) for EOS; and
 - Develop and provide the Information Management System (IMS) for EOSDIS DAACs and the GCDIS data centers.
3. Funding of Science Computing Facilities (SCFs) to enable flight instrument investigators to develop science algorithms for delivery to the DAACs, and also to enable interdisciplinary EOS scientists to analyze data and develop models to study interactions among the various components of the Earth system.
 4. Provision of funding at the DAACs for the local staff that will concentrate on managing the DAAC activities and on developing special services and capabilities for their user communities at the SCFs and elsewhere.
 5. Provision of funding to the DAACs for converting existing data sets into useful data and products (e.g., Pathfinder data sets).
 6. Provision of programmatic support, management, and integration functions within the EOSDIS Project Office.
 7. Provision of funding reserves to ensure the timely development of capabilities for meeting new requirements of the research community or other users.

NASA recently selected Hughes Applied Information Systems, Inc. as the principal contractor for the ECS. As indicated in Table 1, the ECS represents approximately one-third of the total EOSDIS cost.

The panel was encouraged by the allocation of funds for special development at the DAACs. The \$158.2 million is spread over 10 years and eight DAACs, providing \$2 million per year per DAAC. **While this funding is adequate for the present plans for EOSDIS, the expanded role for the DAACs recommended by the panel will require reprogramming of existing funds.**

TABLE 1 Distribution of Funds for the Seven Major Functional Areas Within EOSDIS

EOSDIS Functional Areas	\$Million	%
Data capture and communications	390.0	15
EOSDIS Core System development [Hughes contract]	808.9	32
Science Computing Facilities (SCFs)	312.1	12
DAACs special development activities	158.2	6
Version 0 and Pathfinder data sets	174.3	7
Program support / management / integration ^a	341.2	13
Reserve ^a	372.6	15
TOTAL	2557.3	100

^aThe program support and the reserve line items are each divided into NASA Headquarters and Goddard Space Flight Center components; the numbers given represent the totals.

SOURCE: NASA responses to questions asked by the House Subcommittee on Space (Committee on Science, Space, and Technology) in preparation for the authorization hearings on the NASA FY1994 budget. Figures are for a 10-year period.

The panel was also pleased with the substantial investment being made in Science Computing Facilities. This funding, along with funding from other parts of the EOS program, should make it possible for scientists on the flight instrument teams to provide high-quality algorithms, especially for level-2 data products, as well as participate in DAAC development activities.

EOSDIS CORE SYSTEM COST ANALYSIS

To better understand the nature of the EOSDIS Core System portion that will be developed by the Hughes team, the costs can be broken down into the various elements of the ECS. The panel has been led to believe that NASA and Hughes will soon begin to negotiate a change in the contract. Although the panel does not yet know the dollar amount of the expected change (Change Order #1), the panel has been supplied with the estimated percentages of the total contract allocated to the individual components that can be compared to the costs given for the

baseline contract. The primary change is an increase to the Flight Operations System function and a decrease to the Science Data Processing System. This type of change (which transfers funds away from science processing) can be expected on any mission for which the budget controls are such that trade-offs must be made between science processing and flying the satellite. The costs for the ECS functions are shown in Table 2.

TABLE 2 ECS Development Costs

EOSDIS Core System Functions	Baseline		Change Order #1
	%	\$Million	Estimated %
Project management	11	89.0	10.5
Systems engineering	6	48.5	6.0
Integration/ test	4	32.4	5.0
Science Data Processing System	19	153.7	16.5
Science office	3	24.3	3.0
Communications and systems management	4	32.4	4.0
Product assurance	2	16.2	2.0
Flight Operations System (FOS)	5	40.4	8.0
Maintenance and operations (M&O)	46	372.0	45.0
TOTAL	100	808.9	100.0
SUBTOTAL for development work (excluding project management, FOS, and M&O)	38	307.4	36.5

The \$307.4 million (36.5%) subtotal shown in Table 2 can be characterized as the cost of the detailed design, development, and acquisition effort of the ECS, indicating that the ECS does not involve a large development effort but is more properly described as an integration effort of available commercial, off-the-shelf (COTS) hardware and software coupled to limited development of new software. Thus the panel concludes that the baseline architecture design is essentially an automation of the current system. The panel further concludes

that development and delivery of the ECS, according to its present specifications, within the budget available and on the schedule proposed, have a low risk of technical failure. The panel is concerned, however, that the investment in the development of the ECS will not provide a commensurate return. As planned, the limited functional capabilities of the ECS will not meet the expectations and needs of the user communities.

ARCHITECTURE

The design and development of the ECS to date have focused primarily on receiving, processing, and storing data acquired from satellites and on further processing data using algorithms provided by flight instrument investigators to convert the data to geophysical parameters (see Figure 2). The program has been appropriately sensitive to the need for processing the data routinely even in light of the high data collection rates of space-based sensors. The panel is concerned, however, that the number of standard level-2, -3, and -4 data products (see Table 3) has been substantially reduced and that preliminary plans for standard products (especially levels 3 and 4) are not receiving adequate attention. Based on the briefings the panel received, the plans call for reprocessing of data (especially level-2 data) with improved algorithms only twice in the first 10 years. Similarly, reanalysis of level-3 and -4 data products will be limited.

In the current design, EOSDIS may not have adequate capacity (even with upgrading) to reprocess data with improved algorithms without interfering with the primary objective of moving data from the satellite platforms, through the standard product processing system, to a data archive and retrieval system. This is in contrast to both current practice in other data systems and to researchers' expectations, which require that data products be frequently updated using improved algorithms.

Of particular importance in a redesign of the ECS will be strengthening the feedback between the processing and analysis systems. EOSDIS should facilitate the addition of new processing algorithms to develop higher-order data sets as well as simplify the reprocessing of data based on new algorithms and calibrations. The present approach based on the development of standard data products is essential, but it is too restrictive and rigid; the earth science community cannot anticipate every data product that will be required for global change research for the next 15 years, nor can it wait months to years for new products to be developed.

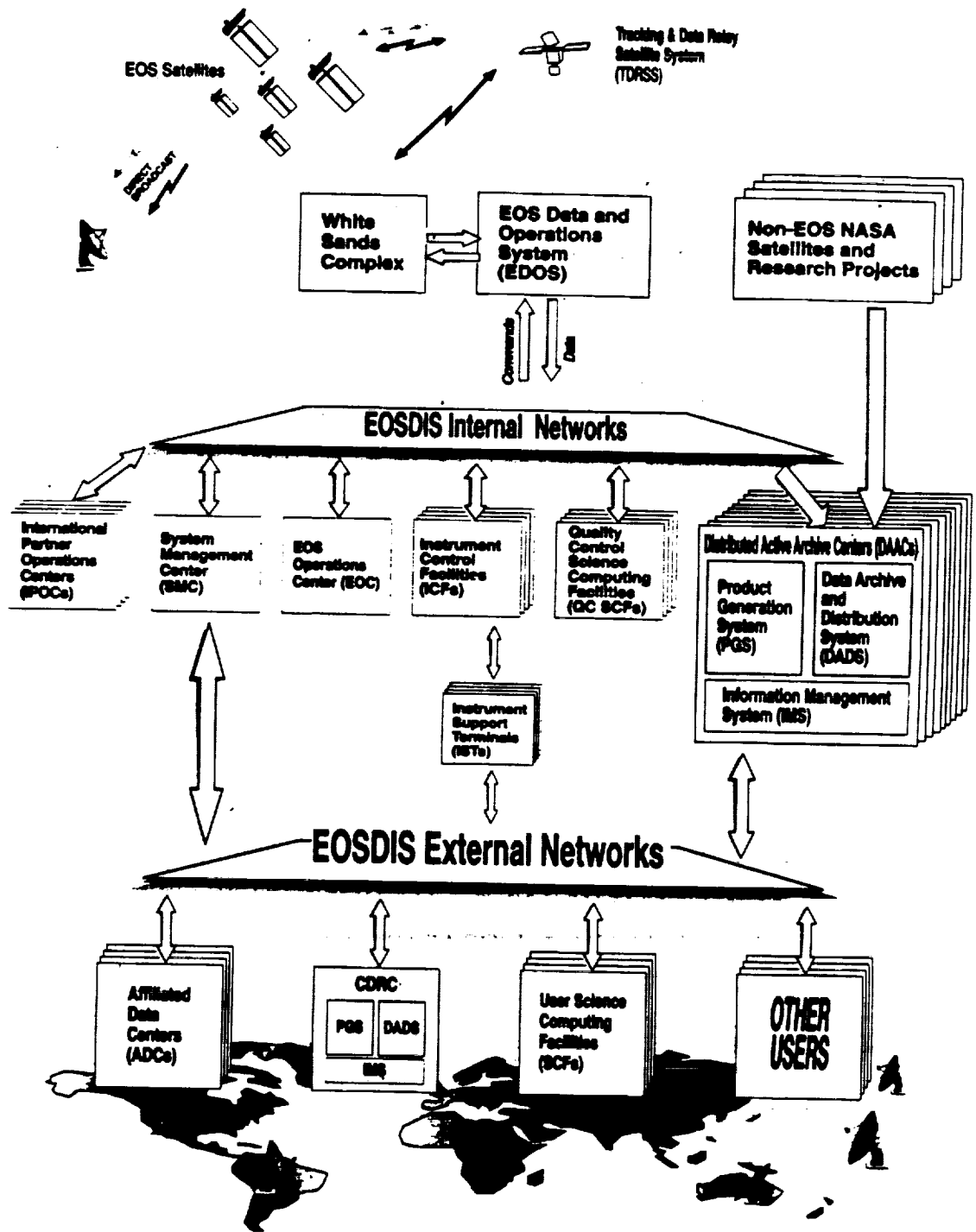


FIGURE 2 EOSDIS Architecture (SOURCE: *EOS Data and Information System (EOSDIS)*, NASA, May 1992).

TABLE 3 Data Product Levels

Level	Description
Raw data	Data in their original packets, as received from the instrument.
Level 0	Raw instrument data at the original resolution, time ordered, with duplicate packets removed.
Level 1A	Level-0 data, which may have been reformatted or reversibly transformed, located to a coordinate system, and packaged with needed ancillary and engineering data.
Level 1B	Radiometrically corrected and calibrated data in physical units at full instrument resolution as acquired.
Level 2	Retrieved environmental variables (e.g., ocean wave height, soil moisture, or ice concentration) at the same location and at a similar resolution as the level-1 source data.
Level 3	Data or retrieved environmental variables that have been spatially and/or temporally resampled (i.e., derived from level-1 or level-2 data products). Such resampling may include averaging or compositing.
Level 4	Model output data that are not directly measured by the instrument but instead are derived from lower-level data, for example, new variables based on a time series of level-2 or level-3 data products.

SOURCE: NASA, *EOSDIS Core System Requirements Specification*, 16 February 1993, pp. A-4 to A-5.

Arrangements should be made so that scientists who are not directly involved in the EOS program are made aware of the existence of algorithms and other higher-order data products not formally developed within the EOSDIS processing and analysis systems. The goal of the EOSDIS product generation system should be to obtain as many good data products as possible within a reasonable level of funding. It also appears that the planning for data product generation has not involved the DAACs to any degree.

NASA should review the product generation function and should involve the principal investigators who develop algorithms, the Distributed Active Archive Centers, and the research community in the review. The review should address the following questions:

- Can the product be best made centrally or in a principal investigator team?
- Are the input data easily available so that product generation will be efficient?

- Could a lower-resolution or sampled data set be used to make it easier to handle global-scale or long-period problems?
- How can timely delivery of products to archives be ensured?

In addition, NASA has indicated a willingness to support only one data format (i.e., high-density format--HDF) for the storage and retrieval of basic data and products. Such a policy will severely hamper effective use of EOSDIS data and products. Not only will it curtail effective use of EOS data, but it is also likely to cause other agencies and users interested in developing compatible database management systems to invest heavily in a format that may not be ideal for their specific use. Instead, NASA should provide effective translators within EOSDIS so that users can easily access EOS and related non-EOS data and products in different formats, including simple character formats and simple binary formats. Most users now obtain small data sets in ASCII format. It is unlikely that the broad range of users will be well served if that option is unavailable.

Moreover, the issue of data archiving needs to be addressed in more detail. The panel understands that NASA plans to store the data for the duration of the EOS program but that no firm decisions have been made regarding their long-term archiving. NASA must make the necessary agreements with archival agencies so that there is no risk that EOS data sets are lost.

The ECS includes data processing, storage, and retrieval components, as well as communications links to and between the DAACs. The DAACs exist today and are generally centers of disciplinary expertise. Most of the DAACs store low-level data, develop and/or distribute data products, and provide user services. Currently, the bulk of the raw data from EOS and many processed data products, perhaps amounting to petabytes, are stored off-line; they are not in a form suitable for storage in current database management systems. A hierarchy of data storage makes sense whereby small, often-used data sets are made available on rapid-access devices and very large, rarely used data sets are stored off-line. The cost of storage for each level in the storage hierarchy must be considered in the decisions that are made.

Under the ECS, the DAACs will utilize a COTS database system to store (over approximately a decade):

-
- Directory data (gigabytes in size): information that allows the user to find what data and information are available, both from EOSDIS and from other sources, and to browse those data visually;
 - Science data products (petabytes in size): information that is constructed by the ECS according to algorithms provided by the user community; and
 - Metadata (terabytes in size): data that describes the raw data elements (e.g., single images--when, where, and how gathered).

The principal form of interaction between users and the EOSDIS system will consist of catalog access, followed by browsing and requests for science data products or raw data sets. There will be only limited opportunity for users to process data at a DAAC. The expected mode of interaction is that data will be shipped to the user, who will then process them, along with data from other databases, locally or at a Science Computing Facility.

Essentially, Hughes is designing and implementing a system to automate the current, largely manual data repository system, in which the archives frequently are off-line, the catalog and browsing capabilities are limited, and the requests for data products are mediated manually. The ECS will automate this repository function, with a resulting improvement in performance, and will uniformly provide certain services such as browsing that have heretofore been available only in isolated cases.

It is important to understand that the ECS, as it is currently designed, will be logically centralized, even though it will be physically distributed among the DAACs. Although the DAACs are centers of disciplinary expertise, they will maintain many similar data sets, as well as similar ECS hardware and software components. The physical distribution of this logically centralized computing system will limit the ability of individual DAACs to evolve and extend the ECS. Although the current plan for the ECS does include provisions to support the development of DAAC-specific capabilities, this plan needs considerable and early input from the DAAC management as well as from the science community.

The ECS will be implemented in a number of stages, called versions. Version 0 of EOSDIS, currently being implemented, will provide an initial product set that will supply users with an early operational capability. Version 0 is being developed as a prototype of selected EOSDIS services. The current plan calls for Version 0 to be abandoned and Version 1 (and following

versions) to be designed and developed separately. **The panel believes that Version 0 should serve as a testbed for further development, rather than be discarded and replaced with a different system. This will allow the development of the ECS to be rational and evolutionary, providing the user community with a well-defined path to a system that will serve their needs.**

The development of an Information Management System (IMS) to provide for interoperability among the DAACs is planned under the ECS. NASA has also agreed to seek the resources to provide an Information Management System for GCDIS. The IMS for GCDIS must meet the needs of many data centers and other repositories, including those of NOAA, the U.S. Geological Survey, the Environmental Protection Agency, and the Department of Agriculture. These data repositories are quite variable in terms of operations and stage of development, whereas the hardware and software for the eight EOSDIS DAACs are being designed and developed centrally. Therefore, the IMS for GCDIS must provide greater flexibility to enhance and ensure the interoperability throughout the GCDIS. **The panel recommends that the Information Management System being developed under the EOSDIS Core System be made more open and extensible and that the Distributed Active Archive Center scientists and relevant data managers from other agencies become intimately involved in the development of the Information Management System for the Global Change Data and Information System.**

The panel believes that an inclusive approach to designing and developing the IMS for GCDIS also would enhance the interoperability among the EOSDIS DAACs, permit the DAAC managers to better serve their users, and engage scientists not directly involved in EOSDIS to improve algorithms and develop higher-order data products.

In light of the investment NASA is making in EOSDIS, the nation has a major opportunity to develop for the first time a high-quality, flexible data information system for the earth sciences. NASA should take a leadership role in assisting other agencies to find ways to take advantage of developments under EOSDIS.

4. EOSDIS Organization, Responsibilities, and Funding Flow

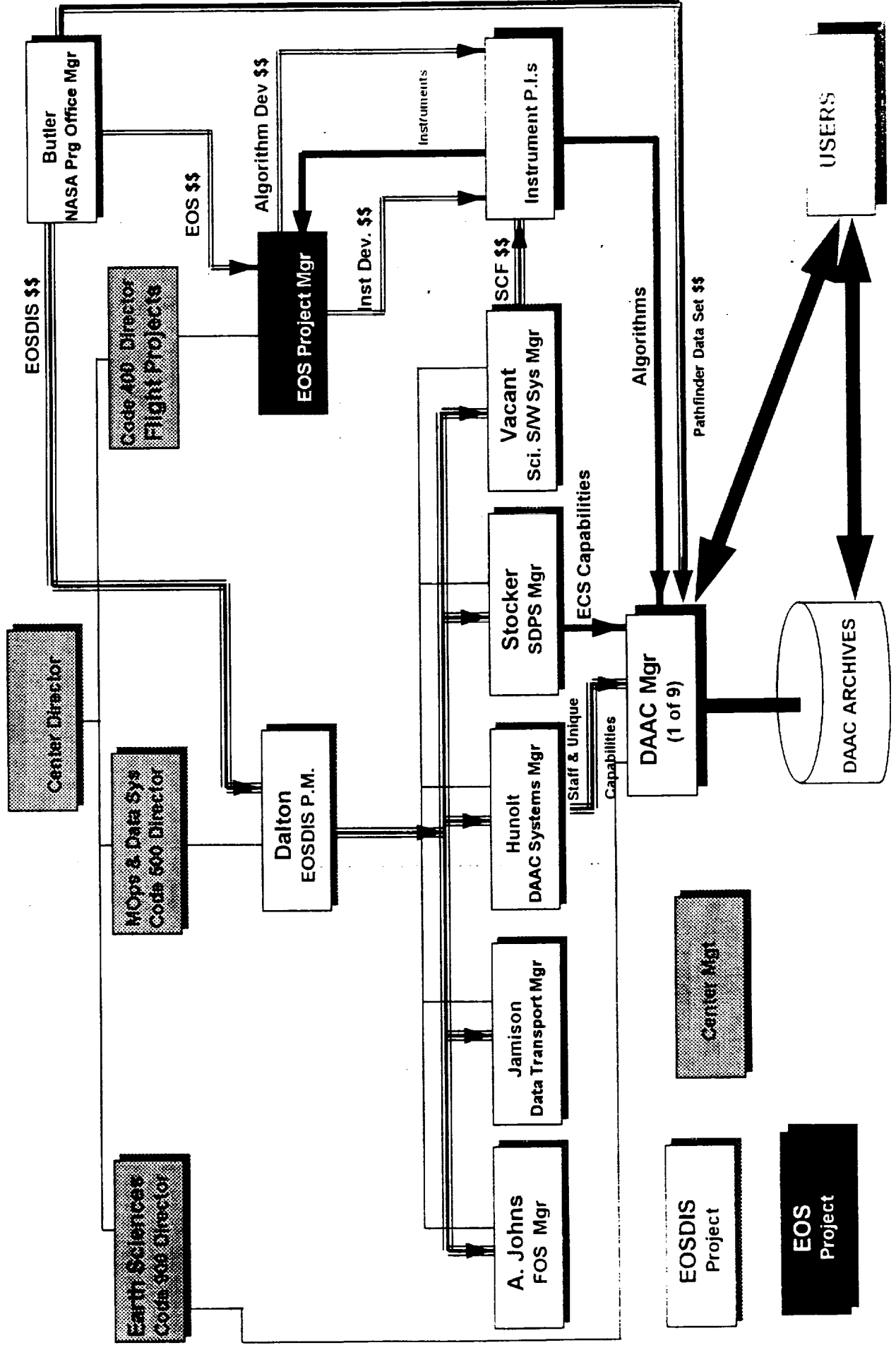
In identifying where all of the elements necessary for EOSDIS are located and funded, the panel developed an illustration of the funding authority and organizational control, as shown in Figure 3. The science component of the EOSDIS project is organized into three key areas that must work together as a team for EOSDIS success. These areas are headed by separate managers: the DAAC systems manager who funds the DAACs, the science software systems manager who funds the Science Computing Facilities, and the science data processing segment manager who funds the ECS itself. (In addition, two managers at the same level within the EOSDIS project manage the functional areas of data transportation and the Flight Operations System). Science managers are organizationally responsible to the EOSDIS project manager from whom they receive funds for their portion of EOSDIS. None of these three managers has responsibility for a data product that, by itself, provides a particular capability to the scientific user. Instead, each useful data product is produced as a result of all three teams working together.

The science users of EOS will look to the DAACs as their primary interface with EOSDIS. Each DAAC will be the responsibility of its own local DAAC manager. The DAAC manager, however, has little influence over the operation and maintenance of the ECS as a whole, has no financial control over the long-term strategy of the DAAC, and has no responsibility to reallocate resources to maximize the services provided to the scientific user. As Figure 3 indicates, any problem or conflict must be resolved either by the three Goddard Space Flight Center managers, who would work together to resolve the issue, or by the EOSDIS project manager.

The flight instrument investigator groups who provide the algorithms to the DAACs are funded by two sources. The SCFs used by scientists and software personnel to develop the algorithms are funded through the EOSDIS project. The funding for the instrument scientists, however, comes from the EOS project, which is in a different GSFC directorate from EOSDIS. Further, the funding for interdisciplinary scientists comes directly from the EOS Program Office at NASA Headquarters. The DAAC manager has no control over either the funding from the EOS project or the funds for the SCFs that flow from the science software systems manager to the instrument investigators, much less the science funding from NASA

Headquarters. This organization, when overlaid with the current funds flow and authority, makes it even clearer that this is a centralized data system that has been physically distributed, and further, that overall coordination of activities within this system will be cumbersome and time-consuming.

FIGURE 3
EOSDIS FUNDING AND ORGANIZATIONAL CONTROL



5. Management Challenges

The panel's previous reports (Addenda A and B) on NASA's plans for EOSDIS identified several concerns, including the lack of:

- Significant experience at GSFC in developing large distributed information systems;
- Adequate involvement of active earth scientists and computer scientists in the EOSDIS project;
- Adequate government control of the system architecture;
- High-level management attention;
- Formal recognition by NASA of the need for making EOSDIS the core infrastructure for a Global Change Data and Information System (GCDIS);
- A logically distributed architecture; and
- Adequate involvement of the DAACs in the development of EOSDIS.

NASA has taken several positive actions in response to concerns expressed in the panel's earlier reports. In particular, the EOSDIS project has been separated from the EOS hardware components, has been given authorization for increased government personnel resources, and has attained a higher level of visibility within GSFC. A computer science research program has been initiated, the DAACs have been given a limited amount of development funds, and the EOSDIS project has taken initial steps to better define the concept of a GCDIS.

Since the first report of the panel, the ECS procurement has been completed, and the panel has been afforded more visibility into the system architecture and the overall EOSDIS project components, work plans, and budgets. **Given its greater understanding of EOSDIS, however, the panel believes that serious management challenges remain. The EOSDIS project still has an inadequate number of senior personnel and system engineering**

capabilities. Several senior project positions remain vacant, including that of the system architect and the information architect. More leadership and experience are needed in the development of large-scale information systems. Furthermore, the earth science community is not sufficiently involved, either in the project office or in the coordination among individual investigators and the SCFs. This coordination is required in several key areas, including the purchase of interoperable equipment at the DAACs and SCFs and the development of science user-oriented software and algorithms. To implement the recommendations of this report, the EOSDIS Project Office must be strengthened by the addition of science managers as well as people having extensive information system architecture and engineering experience.

Although the separation of the EOSDIS project from the EOS flight hardware development is to be commended, the relocation of the EOSDIS project to the Mission Operations Directorate (Code 500) of GSFC suggests that there will remain a strong mission operations bias to EOSDIS, as opposed to a scientific information infrastructure perspective.

These difficulties are compounded by the lack of a user model that clearly defines:

1. Who the EOSDIS customers are;
2. What services these customers will expect and require; and
3. Where in the EOS program the responsibility resides to provide these services.

Arriving at a consensus about all these issues is critical, and the resolution must be reflected in a suitable user model and a science plan, as well as in improved system engineering and management capabilities. For example, although the panel has been told that NASA expects to have 10,000 research users, it is not clear how this number relates to users per month, per year, or over the lifetime of the ECS. In addition, the profile of these users has not been adequately defined.

6. Role of DAACs and SCFs

The panel continues to believe that the DAACs must play a key role in the interactions between the earth science community and EOSDIS. Because the DAACs are data centers, which often include active researchers and which are responsible for implementing user-generated software and supplying services and products to the users, they are, or should be, closest to understanding the diverse needs of EOSDIS users. Thus it can be assumed that the DAACs and their respective user communities represent the real users/operators of EOSDIS. There is no clear plan, however, to incorporate the DAAC expertise and user requirements into the ECS development. The current management of the process to supply the DAACs with the tools and infrastructure they need to fulfill their role is led by NASA Headquarters and multiple elements of GSFC, as noted above, but not by the DAACs and their users.

The panel discussed the roles of the DAACs with EOSDIS project personnel. In addition, it attempted to further understand the status, future plans, and issues concerning the roles of the DAACs in EOSDIS through site visits, presentations, and discussions at several of the DAACs.² The panel discovered a wide variety of perceptions concerning the role of DAACs in the development and operation of EOSDIS:

- The EOSDIS project regards the DAACs primarily as sites for parts of the EOSDIS archives and operations, to be staffed by the prime contractor, and only secondarily as representatives of the users of EOSDIS.
- The diverse science user communities regard the DAACs somewhat suspiciously, seeing them as parts of a still ill-defined and remote EOSDIS.
- The managers of DAACs do not believe that they have much input into the development of EOSDIS or control over their own eventual resources.

² Jet Propulsion Laboratory--August 20, 1993; National Snow and Ice Data Center--August 11-12, 1993; and Oak Ridge National Laboratory--September 1, 1993.

TABLE 4 List of Distributed Active Archive Centers

DAAC	Project Manager	Discipline Responsibility
Alaska SAR Facility (ASF) Fairbanks, AK	Tom George (907) 474-7621	High-latitude SAR imagery, sea ice
Eros Data Center (EDC) Sioux Falls, SD	Lynn Oleson (605) 594-6164	Land process imagery
Goddard Space Flight Center (GSFC) Greenbelt, MD	Paul Chan (301) 286-0828	Upper atmosphere, atmospheric dynamics, global biosphere, geophysics
Jet Propulsion Laboratory (JPL) Pasadena, CA	Don Collins (818) 354-3473	Physical oceanography, air-sea interactions
Langley Research Center (LaRC) Hampton, VA	Roy Dunkum (804) 864-6589	Radiation budget, clouds, aerosols, tropospheric chemistry
Marshall Space Flight Center (MSFC) Huntsville, AL	Cathy LaPenta (205) 544-2755	Global hydrologic cycle
National Snow and Ice Data Center (NSIDC) Boulder, CO	Ron Weaver (303) 492-7624	Cryosphere and polar processes (non-SAR), cryosphere/climate interactions
Oak Ridge National Laboratory (ORNL) Oak Ridge, TN	Larry Voorhees (615) 574-7817	Biogeochemical dynamics, trace gas fluxes, terrestrial/aquatic/marine ecosystem field experiments
Socio-Economic Data and Applications Center (SEDAC) Saginaw, MI	Sam Thompson (517) 797-2686	Human dimension of global change, applications for policy making

SOURCES: Greg Hunolt, DAAC systems manager, Goddard Space Flight Center, *Science Data Plan for the EOS Data and Information System Covering EOSDIS Version 0 and Beyond*, Document Version 2.0, NASA Goddard Space Flight Center, Greenbelt, Md., June 1993.

The panel is concerned that there is no clear responsibility for oversight and coordination of the various science-oriented and "value-added" components of the overall EOSDIS effort. It appears that some \$500 million to \$700 million is allocated to Science Computing Facilities, Pathfinder data sets, and DAAC special development projects. In addition, almost \$1 billion

outside the scope of the EOSDIS project will be spent by NASA for support of EOS science research. Given the strong operations orientation of the EOSDIS project and the ECS as currently defined, these other resources are likely to provide most of the science-user content of EOS. For example, the SCFs are responsible for producing most of the new special-purpose software and custom data analysis results, and presumably much of the most innovative scientific use of EOS. Yet, as noted above, there is no clear plan for coordinating and integrating the work of the SCFs with that of the DAACs and the ECS, or among themselves. There is also no clear plan for coordinated acquisition of equipment and software for the SCFs.

The panel continues to believe that the DAACs are the appropriate entities to represent a large part of the earth science user community. This community consists of diverse elements, each of which may well make different demands on EOSDIS. The DAACs have been chosen in part to reflect this diversity, and additional DAACs should be added to represent new elements and user needs. The DAACs should be empowered to adequately represent their communities and should be given appropriate responsibility and authority. They must be intimately involved in the development, maintenance, and augmentation of the ECS. Ideally, the ECS will supply the infrastructure that will allow the diverse needs of DAACs, SCFs, and other users to be met. The panel reiterates its April 1992 recommendations that DAAC development teams be formed and that the DAACs be given the responsibility, resources, and authority to represent their respective elements of the earth science community. In turn, the DAACs should be charged with interacting with their user communities and understanding their needs and requirements. Finally, the DAACs may need additional personnel to strengthen their management and technical capabilities.

7. Future Evolution of EOSDIS

INTERAGENCY VIEW OF GCDIS³

The Committee on Earth and Environmental Sciences (CEES) was formed to develop the U.S. Global Change Research Program (USGCRP), as prescribed by the Global Change Research Act of 1990. The goals of the USGCRP are to identify the causes and effects of natural and human-induced global change, to predict global change, and to establish a scientific basis to formulate policy decisions. The main elements of the program are

- Documenting global change through the creation of a comprehensive, long-term program of observing and analyzing Earth system change;
- Understanding key processes through focused studies designed to improve our knowledge of the physical, chemical, biological, and social processes that affect natural systems on global or regional scales;
- Predicting global environmental change through the development of models that integrate Earth subsystem interactions; and
- Assessing the scientific, technical, and economic knowledge and implications of global change in order to make global and regional environmental policies.

The U.S. Global Change Research Program is expected to generate unprecedented amounts of diverse and interdisciplinary environmental data that will need to be acquired, assessed for quality, documented, distributed, and archived. Because of the program's complexity and need for a high level of funding, no single data center, agency, or country has the ability to create and manage a global change data and information system. The plan, therefore, is to build on

³ Sources: *Solving the Global Change Puzzle—A U.S. Strategy for Managing Data and Information*, NRC Committee on Geophysical Data, 1991; *The U.S. Global Change Data and Information Management Program Plan*, CEES, 1992; *The U.S. Global Change Data and Information System Implementation Plan (Draft)*, Interagency Working Group on Data Management for Global Change, 1993.

the current data center system infrastructure to create a data and information system that meets the needs of the USGCRP. The data and information management portion (Global Change Data and Information System--GCDIS) of the USGCRP is the responsibility of the Interagency Working Group on Data Management for Global Change, which reports to CEES.

The planned attributes for the GCDIS include:

- Identification of relevant data sets,
- Standardized formats and procedures,
- Data quality assurance,
- Long-term stewardship of data,
- Documentation of data and information (metadata),
- Selective data retrieval,
- Accessibility by the world research community, and
- Creation of data products.

The GCDIS will be distributed among the existing data centers and agency facilities but will use standards agreed on by the agencies. Each agency is responsible for its mission data and information but will also provide certain services in concert with other agencies, such as disseminating global change data in a form that is useful to the research and user communities.

EOSDIS is the largest single component of the GCDIS. NASA has agreed to seek funding to develop the interoperational functionality for implementation of GCDIS by the participating agencies. Under the current design, users access (via Internet) the Global Change Master Directory, which includes summary descriptions of the data and information sets, abstracts and publications relevant to global change research, and location and points of contact for ordering. The directory uses a client-server architecture, with multiple clients accessing a single server. The system is expected to evolve to an architecture involving multiple users, primarily by use of Wide-Area Information Servers (WAIS) or similar technologies.

ROLE OF EOSDIS IN GCDIS

EOSDIS should provide the flexibility needed for global change research by building an extensible Information Management System (IMS) and an extensible Product Generation System (PGS) that could form the basis of a GCDIS. As its primary focus and responsibility, EOSDIS could provide the baseline services necessary to support the needs of the EOS

program. These include flight operations, processing of level-0 to level-1 EOS data, and the development of some standard level-2 products. The IMS and PGS could be extended to include data systems and processing systems that are outside the domain of EOSDIS if this is desired by the GCDIS community. By defining an open interface to the IMS and PGS, these outside systems could in a sense be "registered" with EOSDIS so that all earth science researchers could gain access to them. This open system would go beyond simple interoperability between data catalogs. The implementation of these services would be individual (i.e., they would not have to conform to any rigid standards), yet their interface to the overall system would be open so that users would not need to know the details of their functioning. In this way, a researcher could develop a new set of calibration coefficients for a particular set of EOS data. Another researcher could apply these coefficients to a region of interest simply by requesting the data through GCDIS.

This view of GCDIS involves not only catalog integration, but also data integration and the creation of new data products and sets. **The Pathfinder program (see Appendix A) is a successful example of an interagency effort to create data sets and products that are essential for global change research. These data sets can provide long-term records of observations from both NASA and NOAA satellites. Although the panel did not review this aspect of EOSDIS in detail, it supports a vigorous effort to enhance the quality of previously collected satellite data through reprocessing.**

The development of Internet services such as Gopher and WAIS should serve as models for GCDIS. An open, extensible interface layer provides the foundation for adding various services. Given the clear commercial interest in standards for data exchange,⁴ NASA should rely on developments in the private sector whenever possible; NASA should develop its own standards only if absolutely necessary. The needs of the research community, however, may not be entirely met by commercial companies. In such cases, NASA should take a proactive role to ensure that open standards are developed and incorporated into the GCDIS infrastructure. A similar approach is being taken by the Department of Defense's Global Grid project; it works actively with the telecommunications companies to ensure that proprietary and incompatible standards do not emerge in the development of new networking technologies.

⁴ Commercial standards for distributed architectures are now emerging, for example, the Distributed Computing Environment (DCE) standard and the Object Management Group's specification, Common Object Request Broker Architecture (CORBA).

A guiding principle for the development of GCDIS is that an open interface to the IMS and the PGS should enable other systems to be linked into the overall GCDIS without a significant development effort. Thus, this open interface should not inhibit the addition of new services, but rather should encourage them. Such an approach would encourage a more entrepreneurial flavor in the system.

FUTURE EVOLUTION OF EOSDIS AND GCDIS

One can look further ahead and imagine a user data and information system (UserDIS)--a vision of the National Information Infrastructure (NII) in which there will be a multiplicity of data sources and information integrators available to scientists and others wishing to make use of earth science and global change data. An information integrator in this sense means an information system for producing a product that embodies information collected from several remote sources, for example, a sea-surface temperature data set derived from space-based sensors and multiple in situ and transient surface-based observing systems.

The panel believes that the evolution of EOSDIS toward UserDIS is best addressed not by expanding the goals for EOSDIS, but rather by limiting the ambitions for EOSDIS and relying on the entrepreneurial spirit of the DAACs and other interested organizations, and building on the capabilities provided by advanced networks, such as the NII. In the 1980s, the cost of computation dropped dramatically, which brought about radical changes in the nature of computing and the structure of computing systems. In particular, large numbers of software companies emerged, competing with one another for market share and offering a variety of approaches to computing that had not previously been envisioned. In the 1990s, the cost of communication and switching is likely to drop dramatically, with equally pervasive consequences. The NII, built upon this new communications and switching technology, is expected to offer an entrepreneurial environment in which a variety of products and approaches are made available. Any approach to the collection, organization, and dissemination of earth science and global change data must take this into account.

The NII, as it pertains to earth science research, may be seen as a collection of data sources (the places on the network where information is stored) and integrators (software systems that create an information resource by accepting user queries and obtaining answers by consulting several data sources or other integrators on behalf of the user).

The panel views the NII as a way to tie together the data sources and the information integrators. As planned, the ECS will be primarily a data source, or perhaps eight data

sources--one for each DAAC. The catalog and browsing facilities, however, can be seen as a kind of integrator, since they are intended to provide information about non-EOS data. Given the way the NII appears to be evolving, it may be quite appropriate that the role of the ECS not be expanded greatly and that other ways be found to build an extensible, open system driven by user needs. Indeed, the development of UserDIS may be seen as inevitable, as long as there is no serious attempt to impede it.

Whatever course the evolution of EOSDIS takes, it is important to remember that this data and information system will be one of the most ambitious programs for earth science research ever ventured. The first steps must be carefully designed so that EOSDIS will be able to evolve in such a way as to achieve this potential.

Appendices

- A. The Pathfinder Program
 - B. Acronyms
 - C. Biographies of Panel Members
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Appendix A

The Pathfinder Program

The Pathfinder program was established in 1990 to develop prototype remote-sensing data sets to support global change research and to enable NASA to gain experience in reprocessing and transferring massive data sets between national and international facilities in the pre-EOS era. The data sets consist of long time-series of global and regional data and higher-level data products that were generated by NASA and other federal agencies. Researchers access the data sets and derived products through the DAACs (and participating agencies) under EOSDIS Version 0.

Pathfinder data sets incorporate space-based observations from multiple instruments and include level-0 and -1 data, and land, ocean, and atmosphere products. There are four joint NASA/NOAA Pathfinders, including:

- Advanced Very-High-Resolution Radiometer (AVHRR) Global Area Coverage (GAC): global vegetation, radiance, sea-surface temperature, and clouds and aerosol data and products;
- Television Infrared Observing Satellite (TIROS) Operational Vertical Sounder (TOVS): level-2 and -3 atmosphere data products, such as temperature, radiance, and cloud fraction;
- Geostationary Operational Environmental Satellite (GOES): level-0 data, and cloud and radiation data products; and
- Special Sensor Microwave/Imager (SSM/I): level-1 data, and hydrology, ocean, snow, and ice data products.

Other Pathfinder activities are the joint NASA/USGS/EPA Landsat Pathfinder, which includes land-cover data, and the NASA Scanning Multispectral Microwave Radiometer (SMMR), which includes level-1 data, and hydrology and ocean data products.

Each pathfinder activity has a designated science working group (SWG) that is responsible for identifying what products, algorithms, and user services are needed to conduct research. The SWGs also recommend methods for product generation, validation, storage, and maintenance. It is important for NASA to think about how data integration, especially among multiple DAACs and other agencies, will be funded and achieved.

Appendix B

Acronyms

CEES	Committee on Earth and Environmental Sciences
CIESIN	Consortium of International Earth Science Information Networks
CORBA	Common Object Request Broker Architecture
COTS	Commercial off the shelf
DAAC	Distributed Active Archive Center
DCE	Distributed Computing Environment
ECS	EOSDIS Core System
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EPA	Environmental Protection Agency
FOS	Flight Operations System
GCDIS	Global Change Data and Information System
GSFC	Goddard Space Flight Center
IMS	Information Management System
M&O	Maintenance and operations

NASA	National Aeronautics and Space Administration
NII	National Information Infrastructure
NOAA	National Oceanic and Atmospheric Administration
Pathfinder	A NASA program that will convert existing data sets into information that may be used as a part of EOSDIS
PGS	Product Generation System
SAR	Synthetic Aperture Radar
SCF	Science Computing Facility
SWG	Science Working Group
UserDIS	User Data and Information System
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
WAIS	Wide-Area Information Servers

Appendix C

Biographies of Panel Members

Charles A. Zraket, *Chair*. Scholar-in-Residence, Center for Science and International Affairs, Harvard University. Past President and CEO, MITRE Corporation. S.M.E.E., Massachusetts Institute of Technology; Honorary Doctorate of Engineering, Northeastern University. Member, National Academy of Engineering; Fellow, American Academy of Arts and Sciences, I.E.E.E., AIAA, American Association for the Advancement of Science. **Research interests:** International and national security, global environment, science and technology policy.

Mark R. Abbott. Professor, College of Oceanic and Atmospheric Sciences, Oregon State University. Ph.D., University of California, Davis. Member, NASA EOS Investigators Working Group. **Research interests:** Phytoplankton ecology, satellite remote sensing, advanced networking and information management.

Kenneth I. Daugherty. Deputy Director, Defense Mapping Agency (DMA). Ph.D., Uppsala University, Sweden. Former Assistant and Associate Director, Hawaii Institute of Geophysics; Former Deputy Director, Research and Engineering, DMA, and Director, DMA Systems Center. Fellow, IAG; Recipient, DOD Distinguished Civilian Service Award. **Research interests:** Geodesy, world coordinate systems, advanced surveying/positioning techniques, mapping technology and production systems.

Richard E. Hallgren. Executive Director, American Meteorological Society. Ph.D., Pennsylvania State University. Former Associate Administrator for Environmental Monitoring and Prediction, Assistant Administrator for Oceanic and Atmospheric Sciences, and Director of the National Weather Service. Member, Global Change Research Committee, National Committee for International Decade for Natural Disaster Reduction, Committee on Earth Sciences. **Research interests:** Meteorology, weather systems technology and management.

Elaine R. Hansen. Director, Colorado Space Grant Consortium, University of Colorado. M.S., University of Wyoming. Member, graduate faculty, Aerospace Engineering Department, University of Colorado; Research Associate, Laboratory for Atmospheric and Space Physics. Manager, mission operations for the Solar Mesosphere Explorer. **Research interests:** Solar and atmospheric physics, spacecraft operations, information systems.

John E. Hopcroft. Joseph C. Ford Professor and Chair, Computer Science Department, Cornell University. Ph.D., Stanford University. Member, National Academy of Engineering, NASA Space Science and Applications Advisory Committee, and USAF Scientific Advisory Board. **Research interests:** Algorithms, modeling and simulation.

Roy L. Jenne. Scientific Computing Division, National Center for Atmospheric Research. M.S., University of Washington. Member, Committee on Earth Studies. **Research interests:** Climatology, strategies for developing and accessing data sets for climatological and meteorological research.

Kenneth C. Jezek. Director, Byrd Polar Research Center, Ohio State University. Ph.D., University of Wisconsin. Member, Committee on Geophysical Data, Committee on Glaciology, and Committee on Earth Studies. **Research interests:** Hemispheric-scale observations of the growth, motion, and decay of polar ice using spaceborne instruments.

Thomas R. Karl. Chief, Global Climate Laboratory, National Climatic Data Center, NOAA. M.S., University of Wisconsin. Member, NRC Climate Research Committee, WMO/UNEP Inter-governmental Panel on Climate Change, NRC Effects Subpanel for "The Policy Implications of the Greenhouse Effect." Ex officio Chairman, American Meteorological Society Applied Climatology Committee. **Research interests:** Climate and climate change, Earth system information management.

Edward D. Lazowska. Professor and Chair, Department of Computer Science & Engineering, University of Washington. Ph.D., University of Toronto. Member, Board of Directors of the Computing Research Association, Technical Advisory Board for Microsoft Research, External Advisory Committee for the DOE Pacific Northwest Laboratories Environmental Molecular Sciences Laboratory. **Research interests:** Computer and communication systems.

Ethan J. Schreier. Associate Director for Operations, Space Telescope Science Institute. Ph.D., Massachusetts Institute of Technology. Member, NRC Astronomy and Astrophysics

Survey Committee's Panel on Computing and Data Processing, NASA Astrophysics Division Science Operations Management and Operations Working Group. **Research interests:** Astronomy; observations of x-ray sources, active galaxies, and jets; development and operations of astronomy satellites and distributed data systems for astronomy, including portable software, archives, and networks.

Gael F. Squibb. Manager, Mission Operations Development Office, Jet Propulsion Laboratory. M.S., University of Southern California. Chairman, NASA Astrophysics Data System Study. Jet Propulsion Laboratory: Flight Director, Surveyor Project; Operations Director, Mariner Venus Mercury; Manager, Information Systems Sequence Section; Manager, Infrared Astronomical Satellite Project; Manager, Infrared Processing and Analysis Center; Manager, Advanced X-ray Astrophysics Facility (AXAF) Science Center, Harvard-Smithsonian Center for Astrophysics. **Research interests:** Astronomy, satellite systems.

Jeffrey D. Ullman. Professor and Chair, Department of Computer Science, Stanford University. Ph.D., Princeton University. Member, National Academy of Engineering. **Research interests:** Database systems, especially deductive database systems; database integration.

Addenda

- A. Interim Report, April 1992
 - B. Letter Report, September 1992
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Addendum A

Interim Report, April 1992

NATIONAL RESEARCH COUNCIL

2101 CONSTITUTION AVENUE WASHINGTON, D. C. 20418

OFFICE OF THE CHAIRMAN

April 9, 1992

Mr. Daniel S. Goldin
Administrator
National Aeronautics and
Space Administration
400 Maryland Avenue SW, Room 7137
Washington DC 20546

Dear Administrator Goldin:

Enclosed is an interim report by the National Research Council on NASA's plans for EOSDIS as well as a transmittal letter from the Chair of the Panel that prepared this report. As you know, EOSDIS is a very complex program, and the demands on the Panel that prepared this interim report were extraordinary—in understanding the program, in coping with a demanding schedule, and in reaching judgements. At the same time, my colleagues and I appreciate the importance of EOSDIS. To quote from the attached report: "If EOSDIS fails, so will EOS, and so may the U.S. Global Change Research Program."

It was against such an understanding that the National Research Council accepted this task, believing that we are obliged to assist the government, even when the time is short, the amount of information to be marshalled great, and the imperative to provide judgements urgent.

I believe the Panel that prepared this report has done an exceptional job, ably assisted by the people of NASA. At the same time, the judgements as well as the limits of this interim report should be clear. While the Panel supports the *schedule* for procuring a contractor for the EOSDIS Core System, it finds major shortcomings in the actual plans for EOSDIS, and provides substantial recommendations for implementing the program that the Panel believes will help ensure its success. Therefore, this report cannot be construed as an endorsement of NASA's current plans for EOSDIS, but rather a substantial critique of flaws, which, if addressed, will in the Panel's judgement help ensure a strong and responsive program over the long term. The Panel believes that the terms of the contract as stated in the Request for Proposal are sufficiently flexible to accommodate its recommendations.

The limits of the report should also be plain. It is an *interim* report, provided in response to requests from NASA and other interested parties for an early alert as to the

Panel's views of EOSDIS plans. The Panel's final report this August will offer detailed analyses for these interim judgements, and will also respond directly to the specific issues as posed in the Terms of Reference for this task.

I look forward to your comments on this interim report. And the Panel looks forward to a discussion with NASA officials involved in EOSDIS planning on this report and any further issues to be considered in preparing the final report. We are arranging for your colleagues at NASA with responsibility for the EOSDIS Project to be briefed by the Panel next week, and intend to release it publicly on April 17th.

Yours sincerely,

A handwritten signature in cursive script, appearing to read "Frank Press".

**Frank Press
Chairman**

**cc: L. Fisk, J. Alexander, S. Tilford, D. Butler—NASA
A. Bromley, K. Erb—Office of Science and Technology Policy
J. Hezir, J. Fellows—Office of Management and Budget
S. Harrison—National Space Council
R. Corell—National Science Foundation
Congressman George Brown, R. Byerly, P. Cunniffe—House of Representatives
Committee on Science, Space, and Technology
Senator Albert Gore, S. Palmer—Senate Subcommittee on Science, Technology,
and Space**

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April 9, 1992

Mr. Daniel S. Goldin
Administrator
National Aeronautics and Space Administration
400 Maryland Avenue, S.W., Room 7137
Washington DC 20546

Dear Administrator Goldin:

I am pleased to submit the interim report of the National Research Council's Panel to Review Earth Observing System Data and Information System (EOSDIS) Plans. This contains the panel's preliminary observations and recommendations on the current plans for EOSDIS, based on the information provided. The panel looks forward to an early opportunity to discuss these recommendations with NASA and other interested parties, as well as to issuing its final report in August 1992.

On behalf of the panel, I wish to thank all of those at NASA who responded quickly and professionally to our very substantial requests for information and to our many and often difficult questions. We could not have done our work without their full and ready cooperation.

I also wish to express our gratitude for the splendid cooperation from the staff of the National Research Council that enabled the panel's work on this interim report to be completed in less than two months.

Sincerely,

Charles A. Zraket / *cz*

Charles A. Zraket, Chair
Panel to Review EOSDIS Plans
National Research Council

Panel to Review EOSDIS Plans

Interim Report

This interim report identifies several issues regarding NASA's plans for developing the Earth Observing System Data and Information System (EOSDIS) and offers a number of recommendations that NASA should consider as it proceeds with procuring a contractor to build the system. This report does *not* respond in detail to the items in the terms of reference--that will be the subject of the panel's final report. Given the short time available for the panel's initial assessment, it has not been able to pursue the issues it identified to the depth it would like. The panel hopes, nevertheless, that NASA will find its interim conclusions and recommendations useful in the negotiations that will take place with the selected contractor to define the ongoing work plans for the EOSDIS Project.

The appendices of this report include NASA's letter of request for this study, the terms of reference for the task, a list of the members of the panel and brief biographies, the work done and the meetings held to enable the panel to write this interim report, a brief description of EOSDIS for readers not familiar with the Project, and a brief description of the U.S. Global Change Research Program and its objectives.

The panel was selected to have the competencies demanded by its charge--in understanding the needs of those who will use EOSDIS (including both EOS and non-EOS investigators), in the computer science and technology underlying EOSDIS, in the creation and implementation of large data systems, and in the recent history of large space-based data systems. The fact that the procurement for the EOSDIS Core System was concurrent with the panel's work required extreme care to avoid either the reality or perception of conflict of interest. Thus, in addition to following the National Research Council's standard procedures for dealing with bias and conflict of interest, the panel--and those who provided it information and briefings--took pains to consider only publicly available information. The panel, to the best of its knowledge, has not been provided with nor has it considered any proprietary information related to the procurement.

OBJECTIVES AND MAJOR FINDINGS

In combination with other programs of the U.S. Global Change Research Program, the Earth Observing System (EOS) is intended to reduce the current uncertainties about global climate change. Its Data and Information System (EOSDIS) is essential to the success of EOS. If EOSDIS fails, so will the Earth Observing System and so may the U.S. Global Change Research Program. The panel has been told repeatedly by responsible government officials that EOS is critical to the larger, global change program--one involving many agencies of government, and other national and international participants--and that EOSDIS offers a unique opportunity to begin building a national, and eventually, international, information system for global change research.

To achieve these aspirations, EOSDIS will have to evolve to meet the changing needs of global change research over the next two decades and beyond. The panel believes that the recommendations offered in this report are necessary to ensure that growth and evolution. Specifically, the panel offers its judgments in terms of the following objectives it believes essential to the success of EOSDIS:

- EOSDIS must facilitate the integration of data related to the aims of the U.S. Global Change Research Program. Without this integration, the multidisciplinary and interdisciplinary research objectives of the U.S. Global Change Research Program will not be achieved. The EOSDIS program must be structured and managed to facilitate interactions with the other agencies involved in the U.S. Global Change Research Program so that existing data and future data collected by NASA and by other national and international organizations--using research and operational satellites as well as in situ sources --are available to all global change research scientists.
 - EOSDIS must serve a large and broad set of users to facilitate the aims of the U.S. Global Change Research Program in supporting a community concerned with understanding the earth as a system. To serve that larger community, EOSDIS must provide its information in a manner that is simple, transparent, and inexpensive; it also must assure availability of its data to both the earth science community and the larger scientific community.
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- EOSDIS must ensure that service to current users--including those involved with Version 0--will not be interrupted as the development of the system proceeds, and that Version 1 and subsequent versions will be implemented as soon as possible to meet the needs of the users, both in the EOS program and in the larger U.S. Global Change Research Program.
 - EOSDIS, as it evolves, must maintain the flexibility to build rapidly on relevant advances in computer science and technology, including those in databases, scalable mass storage, software engineering, and networks. Doing so means that EOSDIS should not only take advantage of new developments, but also should become a force for change in the underlying science and technology where its own needs will promote state-of-the-art developments. Flexibility also requires organizational and management structures and processes that can respond to evolving requirements and implement the means for meeting them.
 - EOSDIS needs substantive user participation in the design and development of the system, including involvement in the decisions on data acquisition and archiving, standard or ad hoc product generation, and interfaces that directly affect science users.
 - The structure of the EOSDIS management organization and the attention it gives to the project should reflect the importance of the program in terms of its role as one of the major and most costly programs NASA has ever undertaken as well as its central role in the U.S. Global Change Research Program.

The EOS program was recently restructured from a mission consisting of two large, orbiting platforms containing a total of 30 instruments to a series of six smaller spacecraft containing a total of 20 instruments. The amount of data expected to be collected from EOS, however, has decreased only slightly: from 330 gigabytes/day to 240 gigabytes/day. The estimate for the total amount of processed data (from the EOS spacecraft and the other missions and instruments that will be flown) that will be managed by EOSDIS changed from 1300 gigabytes/day to about 1100 gigabytes/day, a reduction of only 15 percent. Furthermore, the capabilities of the EOSDIS System are tied to the existence of the seven Distributed Active Archive Centers (DAACs) and the data they contain, rather than to the flight rates. Although the panel will certainly examine this issue further for the final report, it appears that the recent restructuring of the EOS flight program has had little effect on the requirements for EOSDIS and thus does not affect the preliminary conclusions of this interim report.

In general, the panel does not see any serious risk to the EOSDIS program due to unavailable or inadequate technology. The panel believes that the prototyping plans of the EOSDIS Project Office, to be implemented after the contractor is selected, should be accelerated in order to assure that Version 1 is completed in accord with design objectives.

There are risks, however, in two aspects of the planning for EOSDIS. One area of risk derives from the scale and pace of changes in computer and data management technology that can be expected over the long-term life of the program, and from the great diversity of users who must interface with EOSDIS. NASA needs to focus immediate attention on planning how EOSDIS will evolve to continue to be a useful system as the scientific needs and the technology change over time.

Another area of risk concerns the management structure of EOSDIS. EOSDIS is an exceptionally large and complicated project that will cost several billion dollars, involve thousands of people, and continue for many years. The management will involve a complex mix of government, contractors, and a scientific community that is diverse and spread around the world. Each has an important role to play, and each will interact in a variety of ways with the other elements. In its recommendations in this interim report the panel has attempted to provide a number of mechanisms and approaches that it believes will help define these roles and interactions.

NASA, of course, must have the ultimate responsibility for implementing EOSDIS. To do so effectively, however, NASA should first ensure proper internal management attention and also should use its own personnel in earth science and computer science, who can contribute significantly to the successful design of the system. Secondly, NASA needs to bring the scientific user community into the project as a partner, rather than regarding users simply as customers. Finally, NASA must accept the leadership role necessary to provide the essential unity among the user community (including other federal agencies and international participants), DAAC elements (management and scientific), and contractors. The complexity of this project demands that a structure be developed to ensure that all interests are properly integrated into the design of EOSDIS.

The panel believes that NASA can proceed prudently with the procurement process for EOSDIS, *provided* the agency builds in the flexibility to make the adjustments necessary to ensure the success of the project. The conclusions and recommendations offered in this interim report can help NASA to incorporate that flexibility into work plans during the contract negotiations that will soon take place. This flexibility can be accommodated within the scope

of the current procurement as long as it is planned ahead of final contract negotiations and the contract terms are compatible with this approach. The panel believes that its recommendations should not materially affect the EOSDIS schedule and that they can be implemented in work plans resulting from the pending contract negotiations. It is important to all users that EOSDIS implementation proceed as closely as possible to the planned schedule.

The panel has divided its assessment into three parts: user interactions, EOSDIS architecture, and EOSDIS management. The recommendations for each area offer actions that NASA should consider in order to meet the objectives of the program described above without halting the current procurement. The panel also recognizes that requirements may change over time and that NASA may have to adjust its work plans over the life of the project.

In order to be of service to NASA during this important stage of negotiating with the selected contractor, the panel believes that it is necessary to provide this advice now, in this interim report. The final report will expand on the issues discussed in this interim report and will respond in detail to the terms of reference.

CONCLUSIONS AND RECOMMENDATIONS

The following are the panel's judgments concerning the user interaction, architecture, and management issues that it believes must be addressed if EOSDIS is to meet the objectives integral to its success. In each instance, the panel points to strengths and weaknesses in the program, and offers recommendations.

USER INTERACTIONS

Strengths

NASA has stated its intention to incorporate user feedback throughout EOSDIS development and evolution. The panel applauds this approach. The ability of EOSDIS to serve the broad spectrum of users will be the final measure of EOSDIS success. In this context, it should be acknowledged that NASA has led other agencies in developing the Global Change Master Directory, which will be a comprehensive description of all global change data sets. The panel also commends NASA for its plan to share software code and toolkits with users who wish to import them for their own systems.

Panel Concerns

In its review, the panel has identified several areas in which an augmentation or strengthening of critical user interactions could substantially improve the likelihood for success of the EOSDIS program. Areas of concern are NASA's Science Data Plan, links with other agencies, use of Pathfinder data sets, treatment of operational and historical data, long-term archiving, involvement of nontraditional communities, and the ability to provide customized data sets.

Science Data Plan. Version 0 science data requirements are being compiled into a Science Data Plan by the EOSDIS Project through regular interactions with the user community. The intent is to solicit regular review of these requirements from the science community to make certain that evolving needs are adequately reflected in the EOSDIS Project planning. Care must be taken to ensure that the Science Data Plan continues to emphasize the links between global change research objectives and the acquisition of individual data sets. A clearer picture of base-level requirements can be achieved by a continuing assessment of science objectives, existing holdings that might meet the objectives, and requirements for future data streams.

The panel recommends that the Science Data Plan identify the links between global change research objectives and existing and planned data sets.

Interagency Links. The research priorities of the U.S. Global Change Research Program cut across the missions of individual federal agencies. The distribution of current holdings as well as data to be acquired underscores the need for interagency interoperability and cooperation. NASA has been an active participant in interagency efforts for the U.S. Global Change Research Program through a variety of working groups, and is currently a full partner in developing a tri-agency (NASA, NOAA, USGS) data and information implementation plan, of which EOSDIS is a critical component. The panel endorses the efforts of these agencies to work cooperatively.

The Global Change Master Directory is an excellent first step in helping users to identify relevant data sets for global change research. A similar effort is needed in achieving interoperability for access to the data. Success will require both technical developments and leadership in order to integrate and provide broad access to disparate data types currently distributed throughout the agencies. The panel believes that NASA is the logical agency to initiate this step in the context of EOSDIS. Moreover, EOSDIS will be much more effective in broadening its user base if it serves as the vehicle for integrating data.

The panel recommends that NASA expand its efforts to increase interagency links by assuming an active leadership role among the agencies in achieving interoperability not only at the level of the Global Change Master Directory, but also at the level of providing access to the actual data.

Pathfinder Data Sets. Prototyping has been a routine component of EOSDIS planning and Version 0 implementation by the Project Office. NASA has been successful in establishing prototype earth science data systems that are currently acquiring, processing, distributing, and archiving pre-EOS data. Lessons from such prototyping activities can identify problems associated with the manipulation and distribution of extremely large data sets.

Pathfinder data sets provide an early means to evaluate the handling of large data sets, the development of products, and the distribution of data and products. NASA and NOAA are cooperating in a Pathfinder data program for selected satellite data. This program will be extremely valuable to the U.S. Global Change Research Program and to the prototyping of various functions of the overall data and information system.

The panel recommends that NASA develop ways to integrate the efforts of existing data centers and centers of data supported by NSF, DOE, and USGS with the NOAA/NASA Pathfinder activities. Further, the Pathfinder data program now under way should be accelerated.

Operational and Historical Data. Data from past and currently operating satellites already are being provided to several DAACs. NASA has shown considerable foresight in recognizing the importance of data streams from NASA, NOAA, DOD, and foreign satellites in establishing long-term data sets for global change research. Although the EOSDIS Request for Proposal addresses data management of NASA's EOS platform instruments as well as NASA's commitment to maintaining data sets acquired by pre-EOS sensors, the panel wishes to emphasize the need for the accessibility of non-EOS instrument data streams to EOSDIS users.

The panel believes that the full benefit of EOSDIS to the U.S. Global Change Research Program will not be realized until an effort similar to that for EOS data is undertaken to manage the immense collection of historical data related to global change research already collected through operational observing systems. This collection includes the routine data from the space-based and surface-based observing systems of NOAA and DOD, as well as the routine and special data collected by USGS, USDA, EPA, DOE, NSF, and the Census Bureau.

Integration, interpretation, and synthesis of such data, as part of a modern data and information system for long-term operational measurement, are critical to the goals of the U.S. Global Change Research Program and the interpretation of EOS measurements.

The panel recommends several ways to address the issue of integrating the operational and research data from other agencies into EOSDIS:

- a. **NASA should articulate a plan for incorporating operational and non-EOS instrument data streams into EOSDIS. Where EOS and non-EOS instruments have similar functions, NASA should develop a strategy to enhance the use of both data streams. This strategy should also include consideration of cross-calibration between basic radiometric data and higher-level products of an EOS instrument with a non-EOS instrument.**
- b. **To test the interoperability of EOSDIS and to integrate the critical long-term operational data that now exist at Affiliated Data Centers into a global change data and information system, NASA should perform a full-function test of the EOSDIS architecture and software on some of the Affiliated Data Centers, in particular, centers with holdings (such as long-term satellite or in situ data records) critical to the U.S. Global Change Research Program and to the synthesis and interpretation of data from EOS instruments.**
- c. **NASA should articulate its policy on how Affiliated Data Centers will move up through the different levels of interoperability that are specified for linkage with EOSDIS.**

Long-Term Archiving. Long-term archiving of EOS data is an issue that has not been addressed. Long-term commitment to maintaining data collected as part of EOSDIS is a critical component of the U.S. Global Change Research Program. NASA, in its response to questions from the panel, correctly pointed out that the issue of maintaining long-term archives is one that must be addressed by all participating federal agencies. Without a concrete plan and agency coordination for establishing permanent data archives, however, the overall objectives of EOS, and, therefore, of the U.S. Global Change Research Program, are jeopardized. As in the case of increasing interagency links, the panel believes that NASA can provide the leadership in addressing this need.

The panel recommends that NASA develop an adequate plan and technology for long-term data archiving in conjunction with the other federal agencies participating in the U.S. Global Change Research Program.

Involvement of Nontraditional Communities. NASA has identified ways for broadening the user community and providing information about EOSDIS to those unfamiliar with the system through professional journals and newsletters. Such publications may be adequate for reaching users in certain disciplines but may be ineffective for those in other fields, particularly in the nonphysical sciences. For example, one of the science priorities identified in the U.S. Global Change Research Program is to assess the human dimensions of global change. A detailed plan for involving potential user communities beyond the traditional disciplines associated with the earth and environmental sciences has not been clearly delineated for the panel.

Many approaches could be taken to encourage users from nontraditional communities (e.g., legal, educational, political, and social). A useful approach could include the distribution of sample products that would allow users to become familiar with the various types of data sets available and to judge whether those data would be helpful to their research.

The panel recommends that NASA take an active role in facilitating access to EOSDIS by other, nontraditional disciplines through a program that includes representatives from those disciplines in NASA's user advisory groups and develops products useful to them.

Customized Data Sets. NASA clearly recognizes the importance of involving the user community in the development of EOSDIS. An approach to encourage active user participation is to provide customized data integration and synthesis of various products. The availability of software tools that conform to standards in an open architecture environment would facilitate participation by active users. For example, these tools might enable a user to assemble a customized set of specific time- and/or space-averaged data that could not otherwise be assembled without the user having to develop new software.

The panel recommends that NASA encourage broad user participation by providing greater opportunities to create customized data sets.

EOSDIS ARCHITECTURE

Strengths

The panel in its several lengthy discussions with EOSDIS technical staff was impressed by the staff's competence and motivation. The staff has devised a process for designing the EOSDIS Core System that would rely on open systems, including multiple levels of interoperability for both users and the DAACs as well as the ability to handle evolving international standards. These two approaches--use of an open system and adoption of standards even though they will change over the lifetime of EOSDIS--will strengthen the program.

The Project plans to deliver EOSDIS in incremental stages (via Versions 1 to 6 and Data Product Levels 0 to 6) that are expected to provide the flexibility necessary to meet user needs, to respond to budget uncertainties over the next decade, and to adjust to EOS flight schedules.

Panel Concerns

Design Control. Any large software system requires design criteria that are set by project management and articulated clearly and precisely throughout the project hierarchy. This is particularly true for EOSDIS because of four reasons: (1) the unprecedented size of the system's storage and processing capacity; (2) the extraordinary heterogeneity of both user computation systems and user requirements; (3) the large variation in scale of both the mass stores and the granules of data to be simultaneously managed; and (4) the high degree of evolution expected in the system. The combination of these factors will make the design, implementation, and evolutionary control of the system a substantial architectural challenge.

Although NASA has assured the panel that EOSDIS will serve the needs of global change researchers, the EOSDIS Core System Statement of Work and the Functional and Performance Requirements documents of the Request for Proposal seem to be based on the management of data holdings resident with or owned by NASA or the DAACs and the created data products related to those holdings. It is entirely likely that data and/or data archives that are not within the exclusive purview of NASA or the DAACs will need to be made accessible to users through EOSDIS, without changing ownership of the data or the autonomy of the data repository. In anticipation of the need for accessibility, EOSDIS software should be built in the form of modular components with open, configuration-controlled interfaces so that other national and international agencies will be able to link with the system and provide products and services to the broader global change research community.

The panel believes that responsibility for the design criteria and for their enforcement to guide the system architecture must reside with the government. The government must assure that the contractor's detailed architecture and implementation decisions follow the directions given by the government system architects.

The panel recommends that NASA produce a clear, concise statement of the design criteria for EOSDIS that focuses on facilitating global change research and that NASA communicate these criteria throughout the Project hierarchy.

The panel recommends that NASA strengthen its internal system architecture team by acquiring additional experienced people and that it give them the responsibility, authority, and budget to ensure that the design criteria are met as the system design and implementation proceed. A technical project of the magnitude and complexity of EOSDIS should have the very best system architecture team possible. NASA should make every effort to acquire such talent.

Logically Distributed System. The research that will be possible through the resources provided by EOSDIS is difficult to characterize at present. Some research will focus on narrow disciplinary questions, while other work will be interdisciplinary. Since we cannot, indeed should not, attempt to specify the future directions that earth science research will take, EOSDIS must be flexible enough to respond to a wide variety of approaches. Furthermore, EOSDIS will be only a part, albeit a major one, of the efforts directed at managing data and information for global change research.

The EOSDIS development plan provides for centralized control over the specification and implementation of the system. Each DAAC will implement an Information Management System that will be centrally developed by a single contractor. Although a centralized system is desirable for the management, operation, and control of the satellite and its instruments, the data will be distributed and dispersed among geographically separate and discipline-specific DAACs. Achieving the proper balance between the common elements that should be developed centrally and those that should be developed in a distributed fashion is critical to the success of the overall U.S. Global Change Research Program. At present, it appears as though the EOSDIS development plan is too heavily oriented toward a centralized approach.

The panel recommends that the EOSDIS Project adapt its development plan to ensure a more logically distributed system, including:

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- a. **Designing EOSDIS so that all users (EOS and non-EOS investigators, DAACs, other data centers) can easily build selectively on top of EOSDIS components. EOSDIS should not constrain local implementation of diverse functions by users and DAACs. The development plan should reflect a philosophy that it is "easy to interact with EOSDIS" with minimum loss of autonomy. EOSDIS must be able to tolerate different versions of functionality and partial sharing of the components and toolkits it exports.**
 - b. **Identifying those areas of interdisciplinary research that will require special interfaces among discipline-specific products and formats. The Project should specify the interfaces, build prototypes, and run simulations to exercise them, permitting users to evaluate them prior to developing final specifications and proceeding to full implementation. A contractor team that resides at each DAAC and works closely with the DAAC as well as the contractor's "central core" team should facilitate the development of these prototypes.**

This type of distributed development can be accomplished within the scope of the current procurement as long as it is planned ahead of final contract negotiation, and contract terms are compatible with this approach.

Incremental Prototyping. The current EOSDIS development plan closely ties the availability of the distributed archive and product generation functions to the EOS flight schedule. There is much work that should be done, however, prior to the first scheduled launch of EOS instruments in 1998 to strengthen prototyping efforts already under way. For example, there are both existing archives and data expected from pre-EOS satellites that will be invaluable to the U.S. Global Change Research Program. Although the EOSDIS Project team has initiated the early prototyping effort for Version 0, more can and should be done to benefit current global change research and to enhance user feedback for final system design.

The panel recommends that EOSDIS Project management extend its incremental development plan so that all user interfaces, all toolkits, and the end-to-end network system are:

- a. **Specified in detail early in the development of Version 1 and prototyped or simulated sufficiently, and**
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- b. **Evaluated in depth by users and DAACs prior to full implementation in Version 1. This will require a system network simulation and sufficient testing tools for users to assess and validate the specified functionality.**

Usability Evaluation. Prudent practice in the design of complex data management systems ordinarily includes a means of measuring the usability of the data. To the extent possible, such measures should be quantitative. Early evaluation exercises should be designed to measure ease of use, quality of interface specifications, and convenience of interoperability of heterogeneous system components. These exercises should ensure that individual users and data archivers can acquire piecemeal both functional capabilities and data sets. It is also prudent practice to involve independent judgment by having this evaluation performed by a group other than those responsible for developing the system.

The panel recommends a usability evaluation program starting as soon as possible that involves:

- **Selecting key functions, interfaces, and system behavior attributes for evaluation;**
 - **Defining a set of metrics and expected values of those metrics for each parameter to be evaluated;**
 - **Creating prototypes, simulations, and test suites to stress aspects of usability;**
 - **Using the evaluations to guide final specification of system components; and**
 - **Implementing this program so that most of the evaluation and validation is done by groups other than the prime contractor.**
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EOSDIS MANAGEMENT

Strengths

NASA is to be commended for developing the plans for EOS as its flagship for U.S. participation in global climate change research. NASA and the EOS Project are further to be commended for their dedication to producing an adequate data system for EOS and for its user community. The unprecedented level of funding allocated for EOSDIS and the high level of planned contingency funding are evidence of the commitment NASA has made to this important national research effort. The panel is impressed with the degree of dedication and commitment of the EOSDIS Project team. The team is working diligently and competently toward both prototyping key system and subsystem capabilities and planning for the procurement of the full EOSDIS system.

Panel Concerns

Visibility and Management Attention. Although EOSDIS appears to receive substantial attention from management at NASA Headquarters, in the panel's view, EOSDIS lacks the attention of senior management at the Goddard Space Flight Center. The EOS Project is the largest single development effort the Goddard Center has undertaken. Even without the flight hardware components, EOSDIS by itself probably satisfies that description. EOSDIS is an extremely complex interdisciplinary science project and must integrate the most advanced data and system technologies. EOSDIS also contains both the flight operations segment and the ground data system. The fact that schedules overlap and that the prime contractor probably will use different groups of personnel to implement these two very different elements will amplify the government's oversight and management challenge. Yet the panel has heard substantial evidence that from the management standpoint, EOS and EOSDIS are treated like an ordinary project within the Goddard Center. For example, the Project Manager for EOSDIS is two management levels down within the Flight Operations Directorate, which is only one of ten directorates at the Goddard Center. In addition, the Project Office is quite small for the task at hand, with plans for only 45 government employees when fully staffed. This small core of dedicated staff provides inadequate programmatic and managerial depth and expertise in the development of large, distributed data systems and in computer science and technology.

Given the preeminent position of EOS and EOSDIS in the U.S. Global Change Research Program, the panel believes that it is essential to increase the level of management visibility of

the Project and the size and skills of the Project staff. In addition to learning from other government agencies that have had experience in the development and operation of large distributed data handling systems, NASA could, as needed, add to the Project experienced systems development personnel from other parts of the government.

The panel suggests that greater flexibility in defining success criteria and in using the process for setting award fees for direct feedback from the Project Manager to senior-level contractor management would help to assure that the contractor will do an outstanding job on EOSDIS. The panel commends NASA for including users in its performance board for contract evaluation and urges the active participation of users in setting award fees.

The panel recommends that the EOSDIS Project Manager have higher management visibility within Goddard Space Flight Center. The staff authorizations and skills should be sized to the scope and complexity of the Project. Further, the Project could augment its staff with experienced personnel from other parts of the government in addition to NASA.

The panel recommends that the EOSDIS Project use the award fee process to best advantage through greater differentiation of success and failure criteria for evaluating contractor performance and by involving users in determining award fees.

Scientific Involvement at Goddard Space Flight Center. The Goddard Center's in-house earth scientists have a very limited role in the management and operations aspects of the EOSDIS Project. Although NASA has established a variety of science advisory and data working groups, such groups cannot replace the continuing and even daily involvement of the external scientific community and the Goddard Center staff to ensure that the eventual system is responsive to user needs.

Likewise, the nation's computer science community currently has very limited involvement in the Project, despite the fact that EOSDIS, to be successful, must implement the latest advances in scientific data management technology and, in some cases, stimulate the development of new technologies. The development of EOSDIS would benefit from substantive use of expertise in systems design and exploitation of information processing technology. Because underlying technologies, such as storage density, processor speeds, and transmission rates, are doubling roughly every three years, EOSDIS must be able to exploit rapidly expanding capabilities during its lifetime of a generation or more.

EOSDIS will also stretch the limits of what can be done by a mammoth database management system shared by a very diverse and demanding user community. Certainly, many of the underlying technologies such as storage will evolve on their own. Other technologies, however, will have to be encouraged, such as large-scale data management, visualization, and integration of heterogeneous information. Possible ways to stimulate technology include establishing an intramural computer science research capability comparable to those in other sciences, supporting and using the external computer science community, and using DAACs to establish formal and informal links with the computer science research community in their neighboring universities.

The panel recommends that NASA involve Goddard Space Flight Center earth scientists to a greater degree in the management and operations of EOSDIS and also involve computer scientists both inside and outside of NASA to explore research and technology in those areas where EOSDIS will stress the state of the art in science and technology and where EOSDIS will evolve most rapidly.

DAAC Involvement. The DAACs are not well integrated into the EOSDIS management structure, particularly during the development phase. The DAAC managers do not have well-defined authority or accountability in building EOSDIS. DAACs should be involved early, in contrast to the current plan, in which their primary role appears to be to operate the hardware and software at their sites after delivery, and to deliver data products to users.

There should be mechanisms for feedback on scientific utility and operational effectiveness from the individual DAACs and associated archive centers to the central Project since the DAACs will be the primary sites for user interaction. There should be a coherent overall development, management, and science advisory structure that includes the DAACs. The panel understands that DAAC managers and scientists are involved in advisory roles. Advisory roles, however, are not sufficient for developing capabilities for and at the DAACs.

Overall, the centralized management of the design and implementation of EOSDIS functions at each DAAC is not conducive to active user involvement and responsiveness to changing technology. What is needed is a structure that strengthens the local role of each DAAC beyond the present DAAC advisory group and thus enhances the responsiveness of each DAAC in meeting the needs of its user community, gives the DAAC some control over its destiny, and yet ensures that an interoperable system is developed to meet the requirements of EOSDIS.

The panel recommends that NASA create, at each DAAC, a Development Team of full-time staff and active science users to address DAAC and user concerns. These teams should evaluate EOSDIS planning and implementation, including architecture, DAAC interface definitions, and other deliverables essential to ensuring that the DAACs will be responsive to user needs and that the EOSDIS system will be interoperable. In accomplishing these tasks, the teams should monitor the contractor's activities on behalf of user communities and prepare test data sets to verify system interfaces. Each DAAC Development Team should validate that DAAC's operational capability to use the evolving EOSDIS system as each of the program releases is implemented. Finally, NASA should provide the DAACs with modest funding to respond to specific user needs so that the DAACs will be able to parallel the evolution of the user community's ability to manipulate, integrate, and model data.

APPENDICES

- A. Letter of Request for Review of NASA's EOSDIS Plans
 - B. Terms of Reference
 - C. Panel Members and Biographies
 - D. Activities of the Panel to Review EOSDIS Plans
 - E. The EOSDIS System
 - F. The U.S. Global Change Research Program
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Appendix A: Letter of Request for Review of NASA's EOSDIS Plans



National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

NOV 22 1991

Dr. Frank Press
President
National Academy of Sciences
Washington, DC 20418

Dear Dr. Press:

NASA is restructuring the Earth Observing System (EOS) program to fly instruments on intermediate and small spacecraft as opposed to a series of large spacecraft. This action will make the program more robust and flexible in the face of future uncertainty and is consistent with the recommendations of a number of groups including the EOS Engineering Review Committee chaired by Dr. Edward Frieman. This restructuring will result in a different sequencing of measurements and changes in the volume of data relative to the original EOS program.

Now that we have a better understanding of how the EOS spacecraft will be configured, it will be necessary to adjust our data system requirements to reflect the needs of the program. Accordingly, as we discussed last week, I would like to request that the Academy undertake a high level review of our plans for the EOS Data and Information System (EOSDIS) to ensure that this effort is compatible with the restructured program and best serves the interests of a broad range of users. The EOSDIS is designed to process, archive, and make readily available the data from EOS as well as data from past, current, and upcoming Earth observing spacecraft that fly in advance of EOS. The user community will depend on this data to develop an understanding of the vital aspects of global change.

Your study should examine some of the fundamental questions regarding the EOSDIS, particularly its responsiveness to the global change research community requirements and its technical feasibility. In addition, you should review the EOSDIS in terms of flexibility and compatibility in addressing evolving requirements, adequate opportunities for user review and input, and balance between distributed and centralized elements.

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NASA is determined to proceed as rapidly as possible with the restructuring of the EOS program in order that there will be no unnecessary delays in program implementation. It is important that your study be accomplished such that an interim or status report can be available to us by March 1992 and a final report of your findings by summer 1992.

I have asked Dr. Lennard A. Pisk of our Office of Space Science and Applications to work with you to define in more detail the terms of reference for this study and to provide full support for your activities. I appreciate your assistance in this important research initiative.

Sincerely,


Richard M. Truly
Administrator

Appendix B: Terms of Reference

The National Aeronautics and Space Administration is restructuring the Earth Observing System (EOS) to be configured to fly on a series of intermediate and small spacecraft, as opposed to a series of large spacecraft. This reconfiguration will result in a different sequencing of measurements and changes in the volume of the data compared to the original EOS program.

The EOS Data and Information System (EOSDIS) is designed to process, archive, and make readily available to a broad range of users the data from EOS and also from appropriate current and upcoming spacecraft that fly in advance of EOS. Accordingly, the EOSDIS architecture will need to be compatible with the program.

The National Research Council will convene a panel of technical experts to conduct a review of NASA's plans for EOSDIS. Members of the panel should be drawn from appropriate National Academy of Sciences and National Academy of Engineering bodies and the technical community in order to bring together a broad mix of expertise in space data systems, data archival and distribution systems and in global change research. A significant proportion of the panel should have expertise in the procurement, technical, and management aspects of large database systems outside the area of global change research. As recommended in the Report of the Earth Observing System (EOS) Engineering Review Committee, the goal of the review should be to validate the engineering and technical underpinnings of the EOSDIS; assess its potential value to scientific users; suggest how technical risk can be minimized; and assess whether current plans provide for sufficient resiliency to be adaptable to changing requirements (i.e., budget environments, data volumes, etc.).

The EOSDIS program is currently selecting an EOS Core System contractor through a competitive procurement. Consequently, access to information by the review panel will be constrained to publicly available documents and presentations. Furthermore, no member selected to participate on the panel should have a significant financial interest in any of the competing contractors.

The panel will review NASA's plans for EOSDIS in order to address the following questions:

- Does the current EOSDIS plan reflect the restructured EOS global change data traffic model (i.e., are EOSDIS features properly sequenced with the complexity of the instruments to be flown and other data sources)? Can/should some of these features be delayed given the current data traffic model?
 - Are the plans for EOSDIS technically realistic and appropriate to meet the information systems demands of the EOS program, with adequate milestones and prototype demonstrations of capabilities? Do these milestones and demonstrations
-

provide adequate benchmarks for monitoring the progress and performance throughout the development and operational phases of the EOSDIS?

- Does the EOSDIS plan meet the requirements of expected research users, especially the global change research community? Do the plans for EOSDIS provide adequately for involving university, national laboratory, government, and other users in influencing the character of each incremental phase of the system?
- Is NASA's plan for the development of EOSDIS sufficiently flexible to match the pace and scope of an observing program that is developed in an evolutionary fashion (i.e., is EOSDIS structured to respond to budget fluctuations or variations in the users demands)? If not, what actions would you recommend NASA taking to address this issue?
- Is NASA's EOSDIS management plan appropriate? For example, is the planned allocation of responsibilities between distributed and centralized elements of EOSDIS conducive to user utilization as well as efficiency and cost effective execution of the EOS program (i.e., is the allocation between distributed and centralized elements optimal)? If not, what actions would you recommend NASA taking to address this issue?
- Is the planning and design for EOSDIS sufficiently flexible to accommodate possible advances in computer hardware and software technologies that may occur over the lifetime of the system? Can/should additional flexibility be built into the design of the database?
- Does the plan for EOSDIS include provision for expansion of the system to include or access other data systems (e.g. National Space Science Data Center, National Geophysical Data Center, Earth Resource Observation System Data Center, and other national and international data systems)? What changes would be required to achieve sufficient flexibility to permit expansion?

Overall, the panel will provide a critical review of NASA's plans for EOSDIS, identify potential problems, and recommend actions that should be taken to address these problems. It will not be expected to offer a redesign of the system.

The panel will provide a status report in March 1992 summarizing the progress of the EOSDIS review, including the principal issues identified by the panel for consideration, and will provide a final report summarizing the findings and conclusions of the review by August 31, 1992.

Appendix C: Panel Members and Biographies**PANEL TO REVIEW EOSDIS PLANS**

Charles A. Zraket, *Chair*, Center for Science and International Affairs, Harvard University
D. James Baker, Joint Oceanographic Institutions Incorporated
Kenneth I. Daugherty, Defense Mapping Agency
Richard E. Hallgren, American Meteorological Society
John E. Hopcroft, Cornell University
Kenneth C. Jezek, Ohio State University
Anita K. Jones, University of Virginia
Thomas R. Karl, National Oceanic and Atmospheric Administration
Ethan J. Schreier, Space Telescope Science Institute
Gael F. Squibb, Harvard-Smithsonian Center for Astrophysics
Jeffrey D. Ullman, Stanford University

Staff

Richard C. Hart, Space Studies Board
Monica B. Krueger, Computer Science and Telecommunications Board
Norman Metzger, Commission on Physical Sciences, Mathematics, and Applications
Lorraine W. Wolf, Board on Earth Sciences and Resources

Biographies of Panel Members

Charles A. Zraket, *Chair*. Scholar-in-Residence, Center for Science and International Affairs, Harvard University. Past President and CEO, MITRE Corporation. S.M.E.E., Massachusetts Institute of Technology; Honorary Doctorate of Engineering, Northeastern University. Member, National Academy of Engineering; Fellow, American Academy of Arts and Sciences, I.E.E.E., AIAA, American Association for the Advancement of Science. **Research interests:** International and national security; global environment, science and technology policy.

D. James Baker. President, Joint Oceanographic Institutions Incorporated; Distinguished Visiting Scientist, Jet Propulsion Laboratory. Ph.D., Cornell University. Member, Global Change Research Committee, Committee on Environmental Research, Climate Research Committee, Joint Scientific Committee for the World Climate Research Program. **Research interests:** Physics of large-scale ocean circulation and climate; ocean and satellite instrumentation; research policy and management.

Kenneth I. Daugherty. Chief Scientist, Defense Mapping Agency (DMA). Ph.D., Uppsala University, Sweden. Former Assistant and Associate Director, Hawaii Institute of Geophysics; Former Deputy Director, Research and Engineering, DMA, and Director, DMA Systems Center. Fellow, IAG; Recipient, DOD Distinguished Civilian Service Award. **Research interests:** Geodesy; world coordinate systems; advanced surveying/positioning techniques; mapping technology and production systems.

Richard E. Hallgren. Executive Director, American Meteorological Society. Ph.D., Pennsylvania State University. Former Associate Administrator for Environmental Monitoring and Prediction, Assistant Administrator for Oceanic and Atmospheric Sciences, and Director of the National Weather Service. Member, Global Change Research Committee, National Committee for International Decade for Natural Disaster Reduction, Committee on Earth Sciences. **Research interests:** Meteorology, weather systems technology and management.

John E. Hopcroft. Joseph C. Ford Professor and Chair, Computer Science Department, Cornell University. Ph.D., Stanford University. Member, National Academy of Engineering, NASA Space Science and Applications Advisory Committee, and USAF Scientific Advisory Board. **Research interests:** Algorithms, modeling and simulation.

Kenneth C. Jezek. Director, Byrd Polar Research Center, Ohio State University. Ph.D., University of Wisconsin. Member, Committee on Geophysical Data, Committee on Glaciology, and Committee on Earth Studies. **Research interests:** Hemispheric-scale observations of the growth motion and decay of polar ice using spaceborne instruments.

Anita K. Jones. Professor and Chair, Department of Computer Science, University of Virginia. Ph.D., Carnegie Mellon University. Member, Defense Science Board. **Research interests:** Computer system design and construction; scientific databases; computer security.

Thomas R. Karl. Chief, Global Climate Laboratory, National Climatic Data Center, NOAA. M.S., University of Wisconsin. Member, NRC Climate Research Committee, WMO/UNEP Intergovernmental panel on Climate Change, NRC Effects Subpanel on "The Policy Implications of the Greenhouse Effect." Ex officio Chairman, American Meteorological Society Applied Climatology Committee. **Research interests:** Climate and climate change; Earth system information management

Ethan J. Schreier. Associate Director for Operations, Space Telescope Science Institute. Ph.D., Massachusetts Institute of Technology. Member, Astronomy Survey Committee Panel on Computing and Data Processing, NASA Astrophysics Division Science Operations Management and Operations Working Group. **Research interests:** Astronomy; observations of x-ray sources, active galaxies and jets; development and operations of astronomy satellites and distributed data systems for astronomy, including portable software, archives, networks.

Gael F. Squibb. Manager, Advanced X-ray Astrophysics Facility (AXAF) Science Center, Harvard-Smithsonian Center for Astrophysics. M.S., University of Southern California. Chairman, NASA Astrophysics Data System Study. Jet Propulsion Laboratory: Flight Director, Surveyor Project; Operations Director, Mariner Venus Mercury; Manager, Information Systems Sequence Section; Manager, Infrared Astronomical Satellite Project; Manager, Infrared Processing and Analysis Center. **Research interests:** Astronomy; satellite systems.

Jeffrey D. Ullman. Professor and Chair, Department of Computer Science, Stanford University. Ph.D., Princeton University. Member, National Academy of Engineering. **Research interests:** Database systems, especially deductive database systems; database integration.

Appendix D: Activities of the Panel to Review EOSDIS Plans

The panel met for the first time on February 14 - 15, 1992, at the National Academy of Sciences facilities in Washington, D.C., to review NASA's plans for EOSDIS. The panel was given the following background material: a copy of the EOSDIS Request for Proposal; summaries of Space Studies Board (SSB) reports on data management and on earth science from space; the 1991 *Report of the Earth Observing System (EOS) Engineering Review Committee* (Frieman report); the 1992 GAO report, *EOS: Information on NASA's Selection of Data Centers*; the 1991 *EOS Reference Handbook* (NASA/GSFC); the report of the Science Advisory Panel for EOS Data and Information, *Initial Scientific Assessment of the EOSDIS*; the CEES report, *Our Changing Planet: The FY1992 U.S. Global Change Research Program*; the 1991 NRC Committee on Geophysical Data report, *Solving the Global Change Puzzle: A U.S. Strategy for Managing Data and Information*; the 1991 SSB report, *Assessment of Satellite Earth Observation Programs, 1991*; and the 1990 NRC Committee on Global Change report, *The U.S. Global Change Research Program: An Assessment of the FY1991 Plans*. The panel also received a draft copy of the GAO report, *Earth Observing System: NASA's EOSDIS Development Approach is Risky*.

During the first meeting the panel received a number of briefings and presentations: (from NASA/HQ) L. Fisk, "EOS Overview"; S. Tilford and D. Butler, "NASA Plans for EOS"; (from NOAA) E. Shea, "Overview of the Global Change Program"; (from NASA/GSFC) J. Dozier, T. Taylor, H. Ramapriyan, and G. McConaughy, "NASA Plans for EOSDIS."

The panel divided itself into three subpanels (User Interactions, Engineering Assessment of System Architecture, and Development/Procurement Process) that each produced a written set of questions for NASA. NASA responded with detailed, written answers. In addition, two of the subpanels visited Goddard Space Flight Center (the Development/Procurement subpanel on February 27 and the System Architecture subpanel on March 5) in order to gain further information from project officials.

The panel met for the second time on March 9 - 11, 1992, at the National Academy of Sciences facilities and heard additional information from NASA (J. Dozier, D. Butler, H. Ramapriyan, and G. McConaughy), a presentation on interagency data management efforts and NOAA data management activities (G. Withee), and a discussion with a DAAC manager (R. Dunkum, NASA Langley Research Center). During this meeting the panel prepared the draft of its interim report.

Appendix E: The EOSDIS System*

The U.S. government has undertaken a multiagency program designed to study the Earth from a global perspective to help develop sound national and international policies related to global environmental issues, particularly global climate change. NASA's contribution to this program is the Mission to Planet Earth, a series of scientific initiatives and spaceflight programs known collectively as the Earth Observing System (EOS). A central element of EOS is the Data and Information System (EOSDIS), a system to make the data obtained from the flight projects and scientific investigations available to the research community.

EOS will consist of a series of spacecraft that will be flown over a 15-year period to investigate the Earth's atmosphere and surface and the interactions between them that could influence global climate changes. Although originally conceived as two large polar-orbiting platforms with 30 instruments, EOS has recently been restructured to six smaller spacecraft with a total of 20 instruments. NASA hopes to fly three copies of each of the spacecraft over the 15-year period. In addition, a number of other U.S. and international space missions will examine various aspects of the Earth's environment. The data produced by this array of spacecraft will need to be processed, stored, and distributed to a research community estimated at 10,000 users. The EOSDIS is being planned by NASA to acquire, process, store, and distribute the spacecraft data; manage the information about the data; provide the networks necessary to access the data as well as the computing facilities necessary to analyze them; provide and maintain the standards and formats for the system; and administer the scheduling of observations and the command and control functions of the spacecraft and instruments. The EOSDIS program is to provide the tools needed to use the data, in activities such as the development and integration of algorithms for scientific products, communication and exchange of data among scientists, archiving of scientific products for access by others, checking on the health and calibration of instruments, and planning and scheduling for acquisition of new data. The system will be expected to manage a data volume of about 600 terabytes/yr.

EOSDIS will be structured around seven research science-oriented Distributed Active Archive Centers (DAACs) that will receive the raw data from the spacecraft, process them, and provide them to the users through a Product Generation System (PGS), which will produce standard sets of earth science data, an Information Management System (IMS), which will give users access to all the data throughout the EOSDIS system, and a Data Archive and Distribution System (DADS), which will serve as the archive and distribution mechanism for the data produced by EOS.

In addition to the Science Data Processing Segment of the DAACs, the architecture for EOSDIS will also include a Flight Operations Segment (FOS) for mission and instrument planning, scheduling, control, and monitoring, and a Communications and System Management Segment for

overall management and coordination of ground system resources such as inter-DAAC communications and interfacing to the NASA Science Internet.

NASA is currently developing a prototype of EOSDIS (Version 0) in order to improve access to existing data and to test the interoperability of existing systems. NASA will select a contractor to develop EOSDIS (Versions 1 through 6) in May 1992, with the expectation of having the full system operating by mid-1998.

*This description has been abstracted from the background material available to the panel (as described in Appendix D) and the briefing documents presented to the panel during the February 14 - 15, 1992, meeting.

Appendix F: The U.S. Global Change Research Program

The U.S. Global Change Research Program (USGCRP) was established as a Presidential Initiative in the FY 1990 Budget to address global environmental issues, with particular emphasis on global climate change. The Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science, Engineering, and Technology is the interagency group charged with the task of developing the program.* The primary goal of the USGCRP is to establish the scientific basis for national and international policies relating to natural and human-induced changes in the global Earth system. In accordance with this goal, the CEES has outlined the following objectives:

- To establish an integrated, comprehensive, long-term program of documenting the Earth system on a global scale;
- To conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence Earth system processes and trends on global and regional scales; and
- To develop integrated conceptual and predictive Earth system models.

The USGCRP is organized around seven science priorities: climate and hydrologic systems, biogeochemical dynamics, ecological systems and dynamics, earth systems history, human interactions, solid earth processes, and solar influences. These science priorities reflect the interdisciplinary approaches necessary for achieving the goal of the Program. In addition to increased understanding in each of these research areas, the success of the USGCRP will require an effective data and information management system. The CEES, through the Interagency Working Group on Data Management for Global Change, is currently planning such a system.

*For a detailed overview of the USGCRP, see: *Our Changing Planet: The FY 1992 U.S. Global Change Research Program*, Committee on Earth and Environmental Sciences (CEES), Federal Coordinating Council for Science, Engineering, and Technology (FCCSET), Office of Science and Technology Policy (OSTP), Washington, D.C., 1991; and *Our Changing Planet: The FY 1993 U.S. Global Change Research Program*, CEES, FCCSET, OSTP, Washington, D.C., 1992.

Addendum B

Letter Report, September 1992

NATIONAL RESEARCH COUNCIL
COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND APPLICATIONS
2101 Constitution Avenue Washington, D.C. 20418

SPACE STUDIES BOARD

Office Location:
Milton Harris Building
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September 28, 1992

Mr. Daniel S. Goldin
Administrator
National Aeronautics and Space Administration
400 Maryland Avenue, S.W., Room 7137
Washington, D.C. 20546

Dear Administrator Goldin:

I am pleased to submit this letter report of the National Research Council's Panel to Review Earth Observing System Data and Information System (EOSDIS) Plans. This letter is based on NASA's responses to the panel's Interim Report of April 9, 1992, two meetings of the full panel (May 15 and July 27-29, 1992), and several discussions between panel representatives and administration officials and congressional staff.

By mutual agreement with NASA, as well as with the Office of Science and Technology Policy, the Office of Management and Budget, and the National Space Council, the panel will now suspend its activities. Agency officials and the panel agreed in July that because a contractor had not been selected for the core system of EOSDIS, the panel could not complete its work. In particular, without knowledge of the critical details of the work to be done by the contractor, the panel cannot respond fully to the questions posed in its terms of reference. The panel remains willing to reconvene once the necessary information is publicly available.¹

The purpose of this letter is to reiterate and elaborate the panel's April 1992 recommendations on several critical areas that require concerted action over the next five to six months if the EOSDIS development program is to proceed on a course that eventually can meet the needs of the Global Change Research Program. The three critical areas are:

1. The development of EOSDIS as an integral part of the Global Change Data and Information System (GCDIS)--in contrast to a program oriented solely to EOS.

NASA is to be commended for its recognition of the critical importance of EOSDIS to the success of the Global Change Research Program. This recognition is reflected in the early and substantial funding for EOSDIS and in NASA's involvement of a broad segment of the prospective user community. The panel is also encouraged by the response to its Interim Report from Drs. Lennard Fisk and Dixon Butler. They stated that NASA intends to implement many of the panel's recommendations, including those that addressed the enhanced development of the GCDIS in conjunction with other agencies and the formulation of Distributed Active Archive Center (DAAC) development teams that will include representatives from the user communities.

Nevertheless, ensuring the success of the program and realizing the benefit of the early and significant funding are now dependent on NASA's establishing firm and specific plans and budgets for the development and operation of the GCDIS, in conjunction with other agencies.

2. **The formation, within NASA, of the management structure and the assembly of skills needed to execute the EOSDIS program and to assure its integration into GCDIS.**
The panel is concerned by the lack of response to and action on to its previous recommendations to strengthen the management--both administrative and technical--of the EOSDIS program. In particular, the panel is concerned that its recommendations for substantial organizational changes in the EOSDIS program seem to have been ignored by management at the Goddard Space Flight Center. The panel believes that, unless these management deficiencies are addressed immediately, the EOSDIS program has a high risk of failure.
3. **The need to strengthen the computer science dimension of the project.**
The panel believes that EOSDIS must be supported by an appropriate computer science research program at a level much greater than currently planned. The panel points out that the costs of an expanded computer science effort would still be a small part of the planned EOSDIS budget, yet could potentially save major costs by avoiding possibly flawed decisions due to inadequate involvement of computer scientists.

Further details about these three critical areas--emphasizing development of a GCDIS, strengthening management, and adequately providing for the role of computer science--are provided below.

THE GLOBAL CHANGE DATA AND INFORMATION SYSTEM

The data essential to fulfilling the multidisciplinary and interdisciplinary research objectives of the Global Change Research Program are widely distributed among national and international agencies. That reality has been recognized by the effort to create a Global Change Data and Information System (GCDIS) by the federal agencies that constitute the Committee on Earth and Environmental Sciences. The purpose of the GCDIS is to simplify the task of obtaining and using data related to global change. The panel believes that EOSDIS must be structured and managed as an integral part of the GCDIS, so that current and future data related to global change collected by NASA and by other national and international organizations are available in an integrated form to all global change research scientists.

These data reside in a variety of media formats and physical locations. Thus, it is essential to have coherent methods for data access that are simple, transparent, and inexpensive to users and that operate at a variety of levels. Providing such methods is a major management challenge. Currently, the GCDIS is being planned in the United States through an interagency group and is intended to exploit the resources and responsibilities of each agency. However, the agencies have widely differing capabilities in information systems technology and management; some lack the necessary resources and finances. Thus, it is not at all certain that, given the complexity and cost of the development effort, a unified and effective GCDIS will emerge. Since NASA is already moving ahead aggressively with EOSDIS, the panel recommends that NASA assume the lead role to plan the overall GCDIS and to

develop the system architecture and network for a truly distributed, interoperable, interagency data system. In doing so, NASA must lead in forming partnerships with the other agencies, including international ones, to develop and operate the various parts of the GCDIS. Such partnerships require continuing dialogue and agreements early on, especially with respect to the operational and funding responsibilities of each participating agency. To facilitate agency cooperation, a national directive should give NASA the leadership role for planning and developing the GCDIS.²

The principles for a national data policy adopted as part of the interagency GCDIS³ incorporate the concept of full international cooperation, both for setting priorities and for establishing standards. The principles are similar to those adopted by the international community as represented by the international Committee on Earth Observations Satellites, the Data and Information System of the International Geosphere-Biosphere Programme, and the World Data Centre System of the International Council of Scientific Unions. The panel endorses this recognition of the international aspect of data management and urges that EOSDIS fully incorporate those principles into its operation.

Having the lead role for implementing GCDIS, NASA will need to obtain a consensus among the participating federal agencies on an implementation strategy. Further, NASA should be prepared to assist other agencies in the design, development, and provision of common GCDIS software, database structures, and technical infrastructure for an interoperable network. Each agency, however, should be responsible for funding the operation and maintenance of its portion of the GCDIS as well as for procuring its own hardware and unique applications software, given that each agency will use the data for other purposes in addition to research on global climate change. The agencies must strive to obtain the funds necessary to accomplish these tasks. Such funds are quite modest compared to the total government investment in the EOS program and, indeed, the entire observational effort required for global change research. It must be kept in mind that the agencies each have resources that are vital to achieving a successful GCDIS; for example, NOAA now has the preponderance of data essential to a GCDIS.

NASA must also develop a philosophy and an overall plan to govern archiving activities and to ensure user input to decisions that affect data retention and the transfer of archiving responsibilities to other agencies. Further, EOSDIS is unlikely to become the vehicle by which a GCDIS evolves if NASA tries to replicate the diversity and volume of databases residing throughout the agencies. It is crucial, therefore, that NASA nurture the active participation of the agencies within the EOSDIS framework.

NASA's EOSDIS Science Data Plan, issued in May 1992, recognizes the significance of NOAA's in situ and space-based climate data and proposes that these data be archived at NASA's DAACs⁴. The panel believes, however, that NASA should not try to duplicate NOAA's database within NASA's DAACs. Instead, the panel recommends that NASA expand by two the number of DAACs, to include NOAA's space-based and in situ data in a truly interoperable, interagency distributed information system, similar to its incorporation of DAACs from the USGS (Earth Resources Observation System, EROS) and from the DOE (the newly established Oak Ridge National Laboratory DAAC).

These NOAA data sets will be critical for adequate interpretation of EOS observations because they enable validation of results and provide a historical baseline to distinguish between natural and

anthropogenic climate change. Again, NASA should not duplicate other agencies' databases, but rather should support their inclusion by developing a GCDIS--a truly interoperable, interagency data and information system.

NASA agreements with participating agencies should be formulated soon; otherwise, it will be difficult for EOSDIS to evolve as a major part of the GCDIS in a coherent and cost-effective way. Effective response will depend critically on federal leadership to assure that each agency participates as a full partner in developing plans and resources for handling its data, supporting its data centers, and facilitating its connection to EOSDIS.

PROJECT MANAGEMENT

The panel remains concerned with the inadequacy of EOSDIS Project management at the Goddard Space Flight Center (GSFC). Some of the key concerns expressed in the panel's Interim Report have either not been understood or cannot be addressed within the existing organizational structure. While the panel again judges the current EOSDIS Project staff to be highly dedicated and technically able, the reality is that the EOSDIS Project does not have the requisite visibility and organizational stature, or the necessary full complement of senior, experienced management and technical staff. Specifically, the project requires management experienced in building complex, integrated data systems costing in the billion-dollar range. Furthermore, EOSDIS is a large-scale distributed information system with goals that extend beyond the EOS flight components. Proper architectural design, technical decision making, and technical risk management must take into account the overall goals of GCDIS. Despite its importance, EOSDIS currently is managed at the GSFC as a standard flight project. Such an approach is unlikely to:

- Incorporate the necessary types and levels of information systems expertise;
- Allow for adequate user involvement in decision-making processes; and
- Provide the infrastructure to attract the expertise and the experienced personnel required to manage a project of this magnitude.

The panel believes that a continued "business as usual" approach will pose serious and unacceptable risks to the successful design, development, and implementation of EOSDIS and certainly of GCDIS. The panel has seen no indication in its discussions with GSFC management that the required changes will be made.

The panel thus recommends that a comprehensive review of the management approach be undertaken immediately. It believes that several ideas should be considered:

- The EOSDIS Project should be elevated to report to the GSFC director and should be independent from the management of the EOS flight components;
- The EOSDIS Project organization should include a leadership role for practicing senior earth observation scientists respected in their research communities;

- The EOSDIS Project staff should have past experience in managing distributed information systems similar in scale to EOSDIS and should include a highly experienced leader of a systems architecture team, a leader greatly experienced in managing the acquisition of large-scale information systems, and senior computer scientists respected in their research communities; and
- The EOSDIS Project Office should contain a specific group charged with maintaining liaison with other agencies and countries involved in global change research in order to facilitate the evolution of the GCDIS.

The panel stresses the need for a strengthened system architecture group in the EOSDIS Project Office to help define an overall information system design that meets user needs and to ensure that detailed design decisions reflect this vision. The panel believes that the EOSDIS Project does not now have such a design philosophy and is relying on the contractor to provide it. For example, in response to a request for a statement of "design criteria," the panel received a list of good software engineering practices that could not be used to distinguish a distributed system from a centralized one, much less to guide the development of a system intended to focus on facilitating global change research. The necessary criteria should be crisply stated, should be user oriented, and should serve to guide day-to-day decision making. Such decisions would include defining important system interfaces and determining the need of end-users for commercial off-the-shelf software versus new specially designed software. The panel believes that a well-defined set of design criteria is an essential management tool.

COMPUTER RESEARCH PROGRAM

Computer scientists must be intimately involved in the development of EOSDIS as well as in EOSDIS Project management decision making. NASA seems to have assumed that by monitoring developments in the commercial sector, it will be able to obtain technology for long-term archiving, network technology, graphics, and other applications. The panel does not agree with this approach. It is likely that adequate hardware and software technology for data storage and retrieval and for data transfer will be available for the initial version of the system. However, the size, complexity, and heterogeneity of the global change data sets will certainly require the development of specialized technology for information management and intelligent query, retrieval, and correlation. The panel concludes that maintaining planned costs and schedules will be jeopardized if EOSDIS is implemented without funding a complementary computer science research program. The project must be prepared to sponsor such research to make long-term enhancements feasible.

The challenges and importance of EOSDIS warrant an investment by NASA in computer science research. In discussions with NASA, the panel has seen increased appreciation of this point but also has observed a misperception of what computer science research is, who does it, and what its payoff is. It is important for NASA to distinguish between research computer scientists and practitioners who are not necessarily researchers. The computer scientists that the panel recommends be brought into the program are active in developing understanding of computing activities, through mathematics and models, based on theory and abstraction.⁵

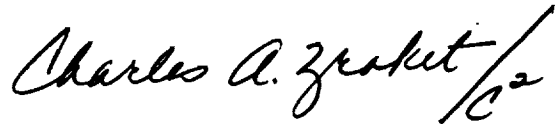
Although supporting computer science research will be a cost factor, the panel believes that NASA runs a greater risk and may potentially incur even greater expense by not supporting such

research. The development and continuing evolution of EOSDIS can be facilitated, and major cost savings achieved, if NASA will now invest in a serious program of computer science research in areas relevant to EOSDIS and GCDIS. NASA should:

- Bring into advisory panels representation from the computer science research community;
- Develop a computer science research program that includes a mix of in-house and external personnel who represent the best the research computer science community has to offer. It is important that a critical mass of expertise be assembled⁶.

On behalf of the panel, I wish to thank all of those at NASA who responded quickly and professionally to the questions submitted by panel members. I would especially like to thank Drs. Fisk and Butler for their responsiveness in devoting much time to useful discussions with the panel on the substance and needs of the program. The panel looks forward to your comments on its recommendations.

Sincerely,

A handwritten signature in cursive script that reads "Charles A. Zraket" followed by a stylized flourish or initials.

Charles A. Zraket, Chair
Panel to Review EOSDIS Plans
National Research Council

cc: L. Fisk, NASA
D. Butler, NASA
K. Erb, Office of Science and Technology Policy
S. Harrison, National Space Council
J. Fellows, Office of Management and Budget

NOTES

1. NASA, in its Statement on Earth Data System Proposals of August 20, 1992, directed the offerers to submit revised cost estimates. Specifically, the NASA announcement stated that "the government's analysis clearly indicates that the offerers significantly underestimated the cost of the respective technical approaches. Accordingly, NASA is unwilling to select an offerer for further negotiations leading to award of a contract." NASA has directed the offerers to submit revised cost estimates by the end of August 1992, with a contract to be awarded by the end of September 1992.
2. The National Space Policy Directive issued by the White House on June 5, 1992, indeed seems to support the eventual integration of NASA data systems into GCDIS, by giving NASA lead responsibility for "Space-based Global Change Observation System" activities.
3. *U.S. Global Change Data and Information Management Program Plan*, Committee on Earth and Environmental Sciences, 1992. An NRC review of the initial plans for GCDIS is described in *The 1992 Data Forum: A Review of a Federal Plan for Managing Global Change Data and Information* (National Academy Press, Washington, D.C., 1992).
4. *Science Data Plan for the EOS Data and Information System Covering EOSDIS Version 0 and Beyond*, Document Version 1.0, May 1992, Goddard Space Flight Center.
5. The new NRC report on computer science and engineering, *Computing the Future: A Broader Agenda for Computer Science and Engineering* (National Academy Press, Washington, D.C., 1992), notes that:

... the "science" in "computer science and engineering" connotes understanding of computing activities, through mathematical and engineering models and based on theory and abstraction.
 ... Computer scientists and engineers focus on information, on the ways of representing and processing information, and on the machines and systems that perform these tasks. (p. 19)
6. Defining what is meant by a "critical mass" is difficult to do. However, the Panel suggests that, based on considerable experience in many projects, an investment of a few percent of a project's Research and Development funds would be a useful way to proceed. Such an investment would provide for, perhaps, 20 to 30 independent computer science researchers to carry out an effective research program that supports EOSDIS development.

PANEL MEMBERS

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